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A SYSTEM ANALYSIS METHOD FOR WATER QUALITY MANAGEMENT BY FLOW AUGMENTATION IN A COMPLEX RIVER BASIN

John Larry Worley

Public Health Service
Portland, Oregon

June 1963

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A Systems Analysis Method for Water Quality Management by Flow Augmentation

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A SYSTEM ANALYSIS METHOD FOR WATER QUALITY MANAGEMENT BY FLOW AUGMENTATION IN A COMPLEX RIVER BASIN

Columbia River Basin Project
Division of Water Supply and Pollution Control
U. S. Public Health Service
Region IX

Developed in cooperation with
Oregon State University as
a thesis by

John Larry Worley

in partial fulfillment of
the requirements for the
degree of

MASTER OF SCIENCE

June 1963

FOREWORD

The work presented herein represents the efforts of many individuals who share a joint interest and concern for the necessity of preserving the quality of water in our rivers. Many workers in the field of stream sanitation have been active in developing computer programs for the analysis of dissolved oxygen relationships in polluted streams. The U. S. Public Health Service, in developing comprehensive pollution control programs for the major river basins of the Nation, early recognized the value of computer analysis as a water quality management tool. Personnel in the R. A. Taft Sanitary Engineering Center at Cincinnati, Ohio, as well as several Public Health Service regional offices directed their attention to different aspects of the problem.

In the early planning stages of the Columbia River Basin Project for Water Supply and Water Quality Management, 1960-1961, efforts were directed at developing a program to analyze the relationships between numerous pollution sources, different degrees of waste treatment, and water inputs to provide streamflows needed to maintain specific water quality objectives in a complex river system.

Technical assistance was requested from the Sanitary Engineering Center, and Professor F. J. Burgess of Oregon State University was retained as a consultant to the project to work on this problem.

A number of conferences were held to develop approaches to the problem. Dr. E. C. Tsivoglou of the Sanitary Engineering Center and Messrs. Jules Cohen and R. L. O'Connell of his staff worked on developing the logic for the program. Professor Burgess and two graduate students, Messrs. K. D. Feigner and J. L. Worley, initiated work related to water quality control by flow augmentation.

Messrs. L. B. Dworsky, J. H. Davidson, J. L. Agee, D. P. Dubois, and R. F. Minnehan of the Public Health Service, Water Supply and Pollution Control Program, Pacific Northwest, all made significant contributions to the program as finally developed.

Grateful acknowledgment is also due the Oregon State Sanitary Authority for supplying stream data and the North Pacific Division, U. S. Army, Corps of Engineers, for providing river data and access to their computer.

Final development and testing of the method was carried out by Mr. Worley as a research and thesis project in fulfillment of the requirements of a Master of Science degree at Oregon State University, under the direction of Professor Burgess. The preparation of the thesis and its application to the Willamette River Basin was completed while Mr. Worley was employed by the Public Health Service, Columbia River Basin Project.

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ABSTRACT

Rapid expansion of population and industrialization in recent years has created new and difficult problems in water resources management. Prudent management of water quality will require that more efficient methods be developed for the reporting and analysis of operational data in a form readily usable by persons responsible for managing complex river systems. The objective of this thesis was to develop a digital computer method which would investigate the dissolved oxygen relationships in flowing streams of a complex river basin; provide for automatic adjustment of flows to maintain desired water quality objectives, in this case, dissolved oxygen; and report results in a rational scheme that is useful to water resource managers.

The computer program herein developed was applied to the Willamette River Basin in northwestern Oregon to illustrate its use. However, it is general in character so that it may be applied to any drainage basin. Three orders of streams including not more than sixty lengths of river (reaches) may be considered in any given study by a computer with sixty thousand digits of core storage. Limitations on the size of the river system which may be considered are imposed by computer storage capacity above the forty thousand digits needed for program use.

The results of this study indicate that:

1. A digital computer using the program developed can, in a few minutes, complete an analysis which would require many man days of manual computation time.

2. The digital computer program developed is a useful tool for investigating the oxygen relationships existing in a river system under present loadings and flows and for predicting the conditions that will be encountered under future loadings.

3. A computer program of this type could be adapted to nearly any of the quality parameters normally considered or possibly a combination of several parameters at such time as mathematical formulations describing their behavior in streams are available.

A SYSTEM ANALYSIS METHOD FOR WATER QUALITY MANAGEMENT BY FLOW AUGMENTATION

INTRODUCTION

The rapid expansion of population and industrialization since World War II has resulted in increasingly difficult problems of water resource management. The most critical of these problems is the protection of our water resources from the ravages of pollution by the discharge of wastes which are increasing in both volume and complexity.

Compounding the problem of increased waste discharge is the decrease in streamflow caused by increased use of water. Some of these uses (such as irrigation) are consumptive. Others (such as power production) are not consumptive but involve holding or storing water in reservoirs for at least part of the year. In either case, the result is usually decreased flow in part of the stream system during part of the year.

Many multi-purpose reservoirs have been constructed for the purpose of managing all phases of the water needs. These include flood control, low flow augmentation for pollution abatement and navigation improvement, power production, recreation, irrigation, and fisheries development. Development for multi-purpose uses has been more common in the Pacific Northwest than in other portions of the country.

The philosophy governing the development of multi-purpose reservoirs has previously been based primarily upon quantity factors that set requirements for necessary water volume. In recent years the importance of managing water resource systems to control quality factors throughout the full length of the region's streams has been recognized as an essential part of wise water resources utilization.

Water quality management must rely primarily upon:

1. The control of pollution by adequate and proper treatment of domestic and industrial wastes.

2. Assimilation of treated waste effluents with adequate flows in the receiving streams.

3. Practices which minimize water pollution problems resulting from agricultural and watershed drainage areas.

Future scientific discoveries may make it possible to treat wastes completely, thereby restoring the water to its original degree of purity. However, technology of waste treatment and construction of waste treatment facilities has lagged behind the pollution problem, and it is not now economically feasible to remove all contaminants from water so that it can be returned to the stream in its original condition. While removal of 85 to 90 percent of the organic pollutants and removal of similar percentages of other contaminants from water is possible by modern-day methods, the resulting waste effluents from such treatment processes still contain significant pollutional loads. As population has increased, the volume of these pollutional loads of treated waste effluents has become sufficiently large to require further methods of treatment for water quality control. This has given rise to the use of low flow augmentation to control stream quality by diluting pollutants with water released from storage in reservoir systems.

Recognizing the importance of low flow regulation of streams, the 1961 Congress amended the Water Pollution Control Act (15, Sec. 2) to provide that:

1. Any Federal Agency involved in the survey, planning or construction of any reservoir shall give consideration to possible benefits to be derived from water quality control by regulation of stream flow.

2. Any such storage and/or releases shall not be provided as a substitute for adequate treatment or other methods of controlling wastes at their source.

3. The Secretary of Health, Education, and Welfare shall provide the other agencies advice on:

a) the need for storage for purposes of water quality control, and

b) the value of storage for water quality control.

The methods for making the requisite water quality studies have been only partially developed. This paper concerns itself with analysis of dissolved oxygen as a quality parameter, since methods for making such an analysis have been well defined by previous investigators (13, p. 18). However, in terms of judging quality, all pertinent parameters should be identified.

Unfortunately, dependable methods for predicting variations in many quality parameters do not exist, and detailed studies considering the variation of these qualities must await suitable mathematical formulation of their behavior in streams.

OBJECTIVE AND SCOPE

To be meaningful, a method for determination and management of water must:

1. Be broad in scope and provide for analysis and management of the entire river system as a unit.

2. Be capable of projection over the economic life of the structures involved.

3. Be able to treat complex systems in a rapid and repetitive manner, making possible studies of a large variety of possible water use plans and pollutional situations in order to provide data for management decisions aimed toward the best possible development.

When applied to complex systems, existing methods of analysis for dissolved oxygen resources versus pollutional loads are so laborious and time-consuming that they prohibit extensive studies. The objective of this paper was established with the above criteria in mind and is stated as follows:

> Development of a digital computer program for the analysis of the oxygen resources of a complex river system for a variety of stream flows and pollution

loadings, such loadings to represent various stages of economic development anticipated in a river basin and stream flows to be those which can be achieved by low flow augmentation through the development of multipurpose reservoirs.

Pollution loadings are assumed to be those reaching the stream after the wastes have received maximum treatment according to the best technology available at the time. The relation of maximum untreated pollution load versus treatment required can, therefore, be determined and will establish waste treatment requirements and influence water resource development of river basins. A general approach to this problem was used so that the program can be applied to any drainage basin. Further, the program has been prepared in such a fashion that only its central core need be changed to consider other quality parameters at some future date when the relationships of their behavior in streams are known and suitable mathematical functions are available to describe such behavior.

A detailed description of the program that has been developed and its application to a river basin is discussed in later sections of this paper. A general description of the calculations performed by the program may be briefly summarized as follows:

1. Input data on stream flow, waste loadings, reaction coefficients and other basic stream data are loaded into the computer which

2. Determines the pollutional situation that will result from the above conditions in terms of dissolved oxygen and

3. Decides whether additional flow is necessary to maintain satisfactory conditions.

4. If flow augmentation is necessary, the computer searches for and adds necessary stream flow, if available, and resolves the entire upstream river system for the new flow conditions.

5. If no extra flow is available, or if none is necessary, the computer continues on to the next downstream section until the study is concluded.

6. Suitable print out of information is provided at the completion of calculations for each river section and at the end of the study.

A complex river basin similar to the Willamette River may contain fifty or more lengths or stretches of river called "reaches" which must be analyzed individually, but are mutually dependent. Since they are mutually dependent, an entire new analysis is necessary when flow and/or waste loading changes are made. A large number of iterations or cycles are therefore necessary for the completed analysis and many man hours of hand calculations would be required. On preliminary or test "runs," an IBM 1620 computer using this program provided the same analysis in a few minutes.

Other digital computer programs proposed for solution of problems of this type are confined to single solution of the oxygen sag equations (4, p. 5-15)(7, p. 3-11) The program presented here has the ability to consider a complete river system, determine flows required to maintain minimum dissolved oxygen concentration, and automatically adjust flows to the required level if storage is available.

Analog computers (6, p. 31-59) have also been adapted to solution of the dissolved oxygen sag equations. However, this type of computer is limited to single solution of a fixed problem and does not provide for automatic flow adjustment.

DISSOLVED OXYGEN RELATIONSHIPS IN STREAMS

The concentration of dissolved oxygen present in a stream is controlled by two opposing reactions. The biochemical utilization of oxygen during degradation of wastes results in a decrease in oxygen concentration and is called deoxygenation. Replenishment of the oxygen is termed reaeration, and is accomplished either through absorption of atmospheric oxygen or photosynthesis. This latter process is not considered in the following developments.

Deoxygenation

The dissolved oxygen content of a stream is intimately related to the biochemical changes which are occurring in the stream (13, p. 5). Deoxygenation has been described by H. W. Streeter and E. B. Phelps as a first order reaction wherein the rate of oxygen utilization is a function of the oxidizable organic matter present. The basic reaction is described in differential form by

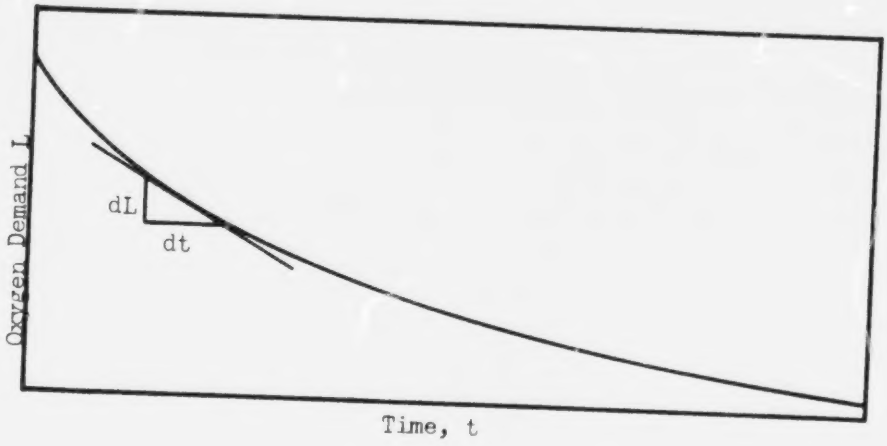


Figure 1. Curve showing relationship of oxygen demand and time.

$$- dL/dt = K_1L \qquad \text{Eq. 1}$$

wherein L is the oxidizable matter present and K_1 is a reaction rate coefficient having the units of 1/days. Time, t, is measured in days. The reaction rate constant is designated K_1 to differentiate it from the reaeration coefficient described in a later section.

The above equation describes the utilization rate of organic matter which, in turn, is measured by its oxygen consuming capacity. The rate of utilization, dL, is therefore equal to the rate of dissolved oxygen utilization, d(DO)/dt, and

$$- dL/dt = d(DO)/dt = K_1L \qquad \text{Eq. 2}$$

Integration of this equation between appropriate limits yields the following useful equations:

$$Log(L_a/L_b) = K_1t \qquad \text{Eq. 3}$$

$$L_b = L_ae^{-K_1t} \qquad \text{Eq. 4}$$

Wherein:

L_a is initial oxidizable organic matter, referred to as initial BOD.

L_b is oxidizable organic matter remaining, referred to as BOD remaining.

e is the base of natural or Naperian logarithms = 2.71828.

K_1 is the coefficient defining the rate of deoxygenation.

t is elapsed time, in days.

The reaction coefficient, K_1, is dependent on the character of the organic substance involved. It has been found that wastes of similar character exhibit similar values of K_1. However, the reaction coefficient can vary widely and knowledge of its value is necessary in application of the equations.

Temperature also influences K_1 to a significant degree. In the range of temperature normally found in domestic and industrial wastes, an increase in temperature would result in an increase in K_1. This relationship has been empirically described by Streeter and Phelps (13, p. 7-8) as follows:

$$K_{1_{(T^\circ)}} = K_{1_{(20^\circ)}} \; 1.047^{(T-20)} \qquad \text{Eq. 5}$$

Reaeration

The amount of atmospheric oxygen that can be dissolved in water is a function of temperature, partial pressure of oxygen in the atmosphere, and salt concentration of the water. Water is said to be saturated when it has absorbed all of the oxygen that can be dissolved in it. The saturation values at various temperatures for chloride free water at one atmosphere of pressure are given in Table 2, (1, p. 312).

TABLE 2

SOLUBILITY OF OXYGEN IN WATER EXPOSED TO WATER-SATURATED AIR*

Temp. °C.	Dissolved Oxygen mg/l	Temp. °C.	Dissolved Oxygen mg/l
0	14.6	13	10.6
1	14.2	14	10.4
2	13.8	15	10.2
3	13.5	16	10.0
4	13.1	17	9.7
5	12.8	18	9.5
6	12.5	19	9.4
7	12.2	20	9.2
8	11.9	21	9.0
9	11.6	22	8.8
10	11.3	23	8.7
11	11.1	24	8.5
12	10.8	25	8.4

*At a total pressure of 760 mm Hg. Under any other barometric pressure, **P** (mm; or **P'**, in.), the solubility, **S'** (mg/l), can be obtained from the corresponding value in the table by the equation:

$$S' = S \frac{P - p}{760 - p}$$

in which S is the solubility at 760 mm (29.92 in.) and p is the pressure (mm) of saturated water vapor at the temperature of the water. For elevations less than 3,000 feet and temperatures below 25° C., p can be ignored. The equation then becomes:

$$S' = S \frac{P}{760} = S \frac{P}{29.92}$$

Dry air is assumed to contain 20.90 percent oxygen.

Where pollution is present, the draft imposed on the oxygen supply by progressive satisfaction of the oxygen demand reduces the oxygen concentration to something less than saturation. When this occurs, the oxygen content is depressed below saturation, and absorption of oxygen from the atmosphere takes place. The rate of reaeration is directly proportional to the saturation deficit, or the amount that the dissolved oxygen content is depressed below saturation. (13, p. 15) The rate at which absorption takes place is defined by the reaeration coefficient, K_2. If K_2 is expressed in terms of saturation deficit, it can be written in differential form as follows:

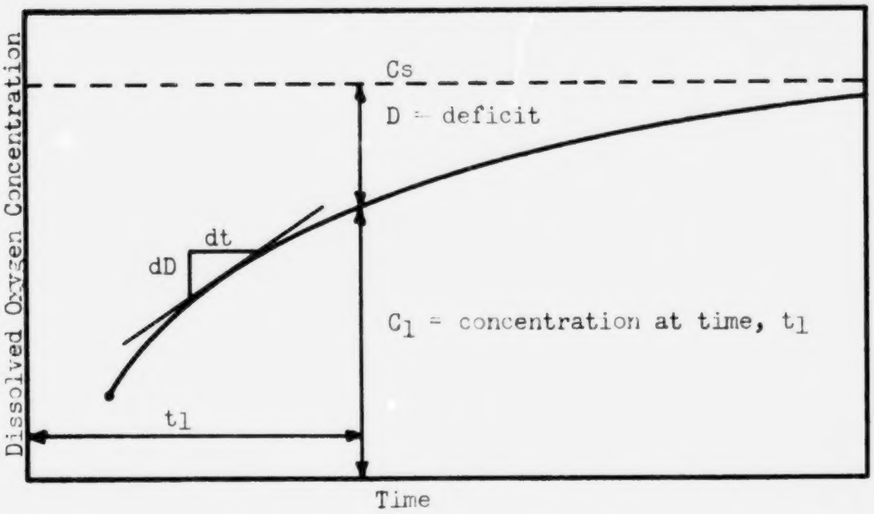

Dissolved Oxygen Concentration
Cs
D = deficit
dt
dD
C_1 = concentration at time, t_1
t_1
Time

Figure 2. Plot showing relationship of reaeration rate curve and time of flow.

$$D = C_s - C \quad \text{Eq. 6}$$

$$dD/dt = -K_2D \quad \text{Eq. 7}$$

Wherein:

C = dissolved oxygen concentration at any time, "t"
C_s = dissolved oxygen concentration at saturation
t is time of reaction in days
D is oxygen saturation deficit of the water
dD/dt is the rate of reaeration, in terms of oxygen saturation deficit
K_2 is a coefficient defining the rate of reaeration

The above equation describes gross effects and must be examined more thoroughly to study the significance of K_2.

Fick's (8, p. 55) diffusion equation has been derived on film theory and concentration gradient considerations and is expressed as:

$$\frac{\partial C}{\partial t} = D_m \frac{\partial^2 C}{\partial x^2} \qquad \text{Eq. 8}$$

Where:

Dm denotes molecular diffusivity (L^2/T)
C denotes concentration of the gas
t denotes time
x denotes distance in the liquid phase.

Examination of this equation indicates that the rate at which a gas diffuses is controlled by both the air-liquid film phase and the concentration gradient in the liquid phase. Diffusion under quiescent conditions is so slow as to be negligible as a source of oxygen in a pollutional situation. Stream turbulence, which greatly increases the concentration gradient in the surface film and mechanically carries water from the surface to a depth, is of major significance in oxygen transfer.

Several methods which consider both turbulence and depth factors have been suggested for estimating a gross value for K_2. For the work of this thesis, the method proposed by D. J. O'Connor (10, p. 35-36) has been selected. This choice is arbitrary as other methods of determining K_2 could have been used with comparable success.

There are two forms of O'Connor's equation and are as follows:

$$k_2 = 480 \frac{D_L^{1/2} S^{1/4}}{H^{5/4}} \qquad \text{Eq. 9}$$

$$k_2 = \frac{(D_L U)^{1/2}}{2.31 H^{3/2}} \qquad \text{Eq. 10}$$

Where:

k_2 is to base 10
D_L = coefficient of diffusion of oxygen in water in square feet/day
U = velocity of forward flow in feet per day
H = depth of flow in feet
S = slope of channel in feet per foot
480 incorporates the necessary dimensions and constants

Equation 9 is for use on relatively shallow streams with non-isotropic flow, and equation 10 is for relatively deep streams with flow characteristics which approach isotropic (the same in all directions) conditions.

There is some question as to what constitutes a deep stream or a shallow stream. Dr. O'Connor (9, p. 17)(10, p. 36) has used the Chezy coefficient, C, as a criterion to differentiate between shallow and deep streams and suggests a C of 17 as the dividing line between isotropic and non-isotropic flow. A sharp line of demarcation does not exist, but rather a gradual transition, probably defined by a range of C from 14 to 20.

Basic Hydrologic and Physical Data Required

The Willamette River basin has been used as the river system for development of the oxygen sag program dealt with in this thesis. This selection was made because data on waste loadings and hydrologic data needed for evaluation of parameters such as K_2 are relatively abundant. To determine K_2, river cross-section data for three stages of measured flow were obtained from the U. S. Army Corps of Engineers and used to calculate average depths and velocities for the main stem of the Willamette. The average depth was taken to be cross-sectional area divided by surface width, and the average velocity was obtained by dividing the measured flow in cubic feet per second by cross-sectional area. When specific data were unavailable, slopes were obtained from United States Geological Survey river profile sheets or contour maps and depths were estimated to allow calculation of a value for K_2. Values of the diffusion coefficient, D_L, were obtained from two sources (5, p. 446)(12, p. 174) and an average value of 1.70×10^{-3} ft^2/day was used.

These values were used in O'Connor's equations to evaluate K_2 for each reach in the river system. An equation developed by Churchill, et al, (3, p. 34) was also used to calculate a k_2 for each reach. This equation is stated as follows:

$$k_{2_{(20°)}} = 5.026 V^{0.969} R^{-1.673} \qquad \text{Eq. 11}$$

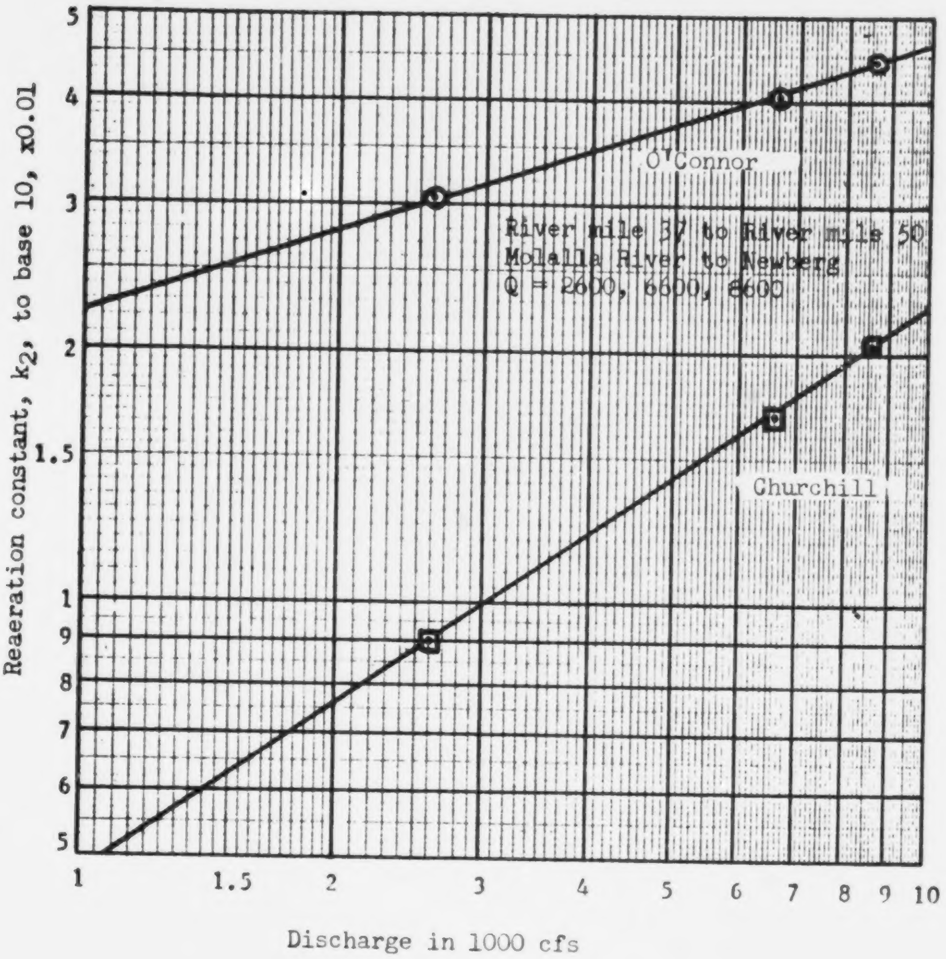
where V is mean velocity in feet per second and R is mean depth in feet. When k_2 had been computed for each reach by both methods and for three stages of flow, plots of k_2 versus flow were made on log-log paper (see Appendix) and yielded the relationship shown in Figure 3. Since k_2 will vary with flow, an equation to describe this relationship was necessary for use in the computer program to recalculate k_2 when changes in flow occur. It was found that an equation of the form

$$k_2 = aQ^b \qquad \text{Eq. 12}$$

could be written from the straight line relation obtained on log-log paper. If "a" and "b" are determined for each reach, then Q is the only variable required to evaluate k_2 in this program. No extensive work has been done to verify the relationship used above, but it was reasoned that so long as a river remains within its natural banks, such a relationship would be sufficiently valid for practical use. This latter condition will always be satisfied during low flow-critical dissolved oxygen periods.

An equation of the same form was developed to relate velocity of forward flow to flow. This equation was also developed from log-log plots (see Appendix), and is written as

$$V = cQ^d \qquad \text{Eq. 13}$$



Discharge in 1000 cfs

$b = 120/376 = 0.319$

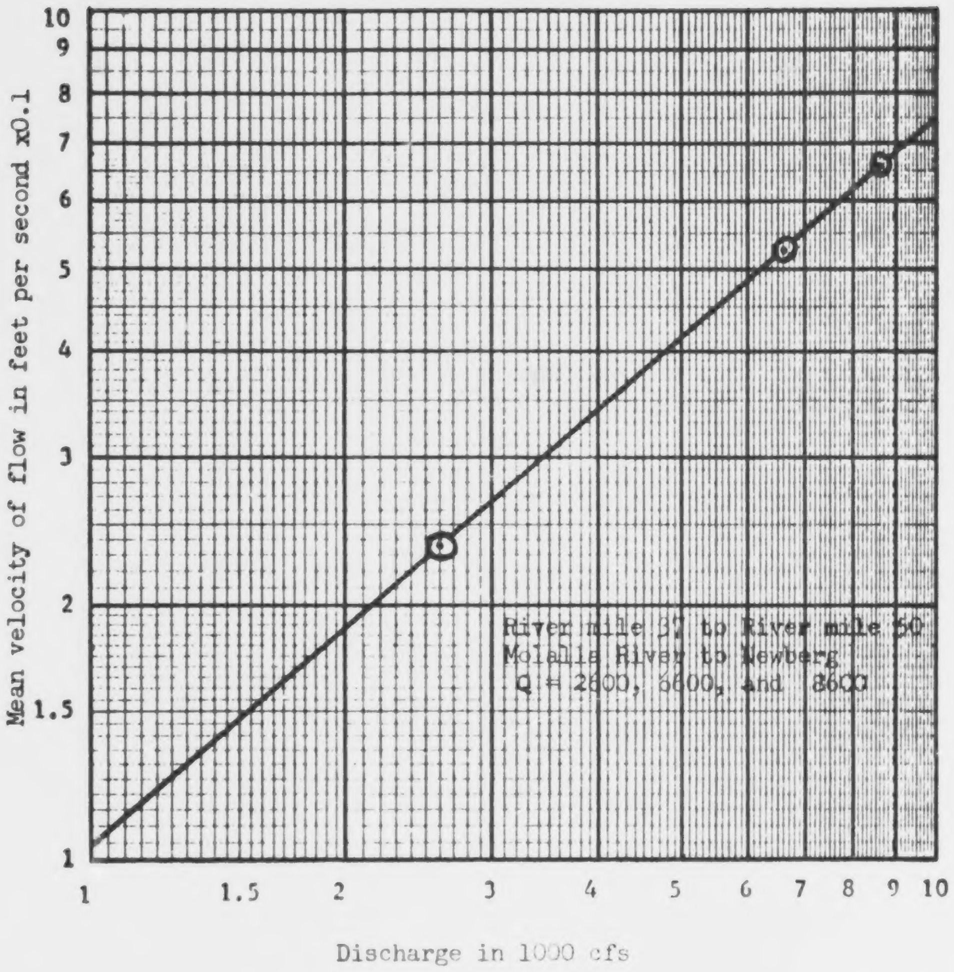
$k_2 = 0.0275$ when $Q = 1950$

$0.0275 = aQ^b$

$a = \frac{0.0275}{11.2} = 0.002455$

So $k_2 = 0.002455\ Q^{0.319}$

Figure 3



$d = 323/376 = 0.859$

when $Q = 1350$, Vel. $= 0.135$

$0.135 = cQ^{d}$

$c = 0.135/490 = 0.0002755$

So $V = 0.0002755\ Q^{0.859}$

Figure 4

The results of this computation together with distances along the river facilitated calculation of travel times.

Data are relatively complete for the main stem of the Willamette River, but many data are missing for tributary and branch streams. Where data were lacking, an estimate was made for K_2 or velocity. When an estimate had to be used in the program, the method employed was to set the estimate equal to the coefficient in the K_2-flow or velocity-flow relationship and the exponent was set to zero. Since the exponentiation is performed first by the computer, this allowed the estimate to appear as the final value for K_2 or velocity. Both the coefficient and the exponent are entered into the program on data cards, so they can be easily changed or corrected at a later date when more accurate data become available.

Temperature effects must also be considered in evaluating K_2. An empirical formula (2, p. 378) relating K_2 at 20° C to K_2 at other temperatures has been developed as follows:

$$K_{2_{(T^\circ)}} = K_{2_{(20^\circ)}} \quad 1.0159^{(T-20)} \qquad \text{Eq. 14}$$

Since, in this program, temperature for each reach remains constant during the complete solution of the river system analysis, the easiest method of applying a temperature correction is by incorporating it with the coefficient, "a", in the K_2-flow relationship.

Response to a Pollutional Load

The net effect of a stream's response to a pollutional load may be shown by graphical illustrations (Figure 5 and Figure 6) of the deoxygenation-reaeration relationships as follows:

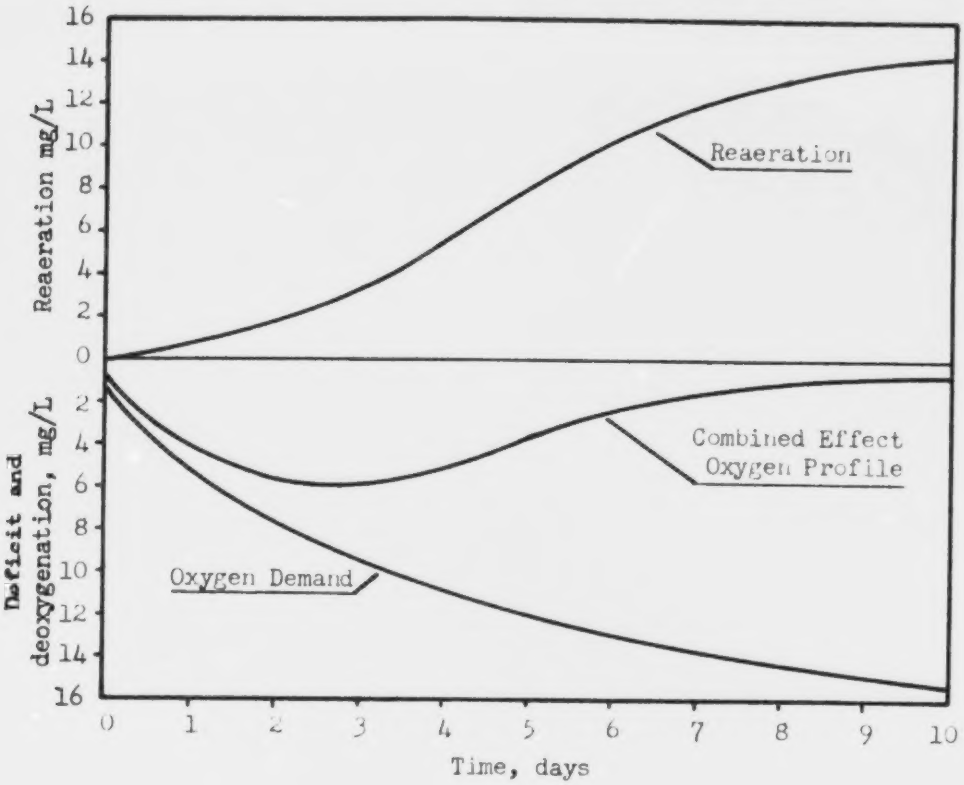


Figure 5. Curves showing combined effects of deoxygenation and reaeration.

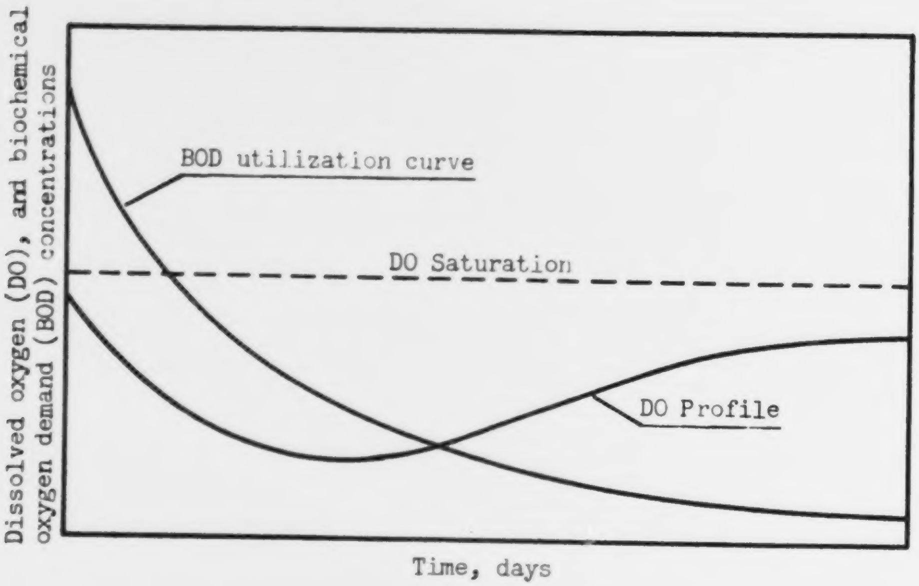


Figure 6. Plots showing utilization of biochemical oxygen demand and its relationship to the dissolved oxygen profile.

A summation of deoxygenation and reaeration describes the response of a stream to a pollutional load and can be expressed mathematically (13, p. 17-18) as follows:

$$dD/dt = K_1L - K_2D \qquad \text{Eq. 15}$$

When this equation is integrated it becomes:

$$D = \frac{K_1L_a}{K_2 - K_1}\left(e^{-K_1t} - e^{-K_2t}\right) + D_ae^{-K_2t} \qquad \text{Eq. 16}$$

Wherein:

D_a = initial dissolved oxygen saturation deficit of the water
D = saturation deficit after an elapsed time, t
L_a = initial oxygen demand of the organic matter in the water
K_1 = coefficient defining the rate of deoxygenation
K_2 = coefficient defining the rate of reaeration
t = elapsed time, in days
e = base of natural or Naperian logarithms = 2.71828

Summary of Equations

The following short summary and discussion of the mathematical expressions involved in describing how a stream responds to a pollutional load is presented prior to the use of these equations in the succeeding portions of this thesis.

Biochemical Oxygen Demand. The amount of dissolved oxygen used by bacteria for respiration in utilizing organic matter for food can be expressed as follows:

$$-dL/dt = K_1L \qquad \text{Eq. 17}$$

$$L_b = L_a e^{-K_1 t} \qquad \text{Eq. 18}$$

Wherein:

t = elapsed time, in days
L_b = oxidizable organic matter remaining referred to as BOD remaining
L_a = initial oxidizable organic matter referred to as initial BOD
e = the base of natural or Naperian logarithms = 2.71828
K_1 = coefficient defining the rate of deoxygenation

In terms of oxygen utilization, deoxygenation can be expressed as follows:

$$dD_1/dt = K_1L \qquad \text{Eq. 19}$$

Reaeration of Streams. A mathematical expression of reaeration in terms of saturation deficit can be written as follows:

$$dD/dt = -K_2D \qquad \text{Eq. 20}$$

Wherein:

D = saturation deficit
t = elapsed time
K_2 = coefficient defining rate of reaeration

Response to a Pollutional Load. A summation of deoxygenation and reaeration describes the response of a stream to a pollutional load and can be expressed mathematically as follows:

$$dD/dt = K_1L - K_2D \qquad \text{Eq. 21}$$

Integration of this expression yields:

$$D = \frac{K_1L}{K_2 - K_1}\left[e^{-K_1t} - e^{-K_2t}\right] + D_ae^{-K_2t} \qquad \text{Eq. 22}$$

The above equations do not include oxygen demand by sludge deposits and miscellaneous organic loads entering from land drainage, tree leaves, etc. Since the sludge load and bank load can exert a significant influence, the above equation was modified (14, p. 3-5) to include them as follows:

$$D = \frac{K_1L_a}{K_2 - K_1}\left(e^{-K_1t} - e^{-K_2t}\right) + \frac{24B_LV}{K_2}\left[\frac{K_2(1 - e^{-K_1t}) + K_1(1 - e^{-K_2t})}{K_2 - K_1}\right]$$

$$+ \frac{24S_LV}{K_2}(1 - e^{-K_2t}) + D_ae^{-K_2t} \qquad \text{Eq. 23}$$

Wherein:

D has units of L_a & $\frac{B_LV}{K}$ & $\frac{S_LV}{K}$ & D_a

if D = mg/L

B_L & S_L = (mg/L) per mi

D = saturation deficit after an elapsed time
L_a = initial BOD of the stream
K_1 = coefficient defining rate of deoxygenation
K_2 = coefficient defining rate of reaeration
e = base of natural or Naperian logarithms = 2.71828
t = elapsed time, in days
24 = constant to convert miles per hour to miles per day
B_L = bank load which has been defined as a uniform oxygen demand such as tree leaves, etc., which may enter the stream along its banks
V = velocity of stream flow in miles per hour

S_L = sludge load which has been defined as the oxygen demand imposed by the benthal deposits on the stream bottom
D_a = initial saturation deficit of the stream

Other equations developed (14, p. 3-5) for use in this program are expressions for critical time and critical deficit and are as follows:

$$t_c = \frac{1}{K_2 - K_1} \log \left[\frac{L_a K_1 K_2 + (K_2 - K_1)(24 S_L V - D_a K_2) - 24 B_L V K_1}{K_1^2 \cancel{D_a} L_a - 24 B_L V K_1} \right] \quad \text{Eq. 24}$$

$L_a K_2$

? incorrect! Not consistent with equation used in program, see page 72 & listing in appendix. JLP

$$D_c = \frac{D_a e^{-K_1 t_c} + 24 B_L V (1 - e^{-K_1 t_c}) + 24 S_L V}{K_2} \quad \text{Eq. 25}$$

Where:

t_c = time in days to critical point in dissolved oxygen sag
D_c = saturation deficit at critical point in dissolved oxygen sag
All other terms are the same as defined for Eq. 23 above.

These equations are also standard forms modified to include sludge load and bank load. Such modifications were used to allow more complete analysis when data for sludge load and bank load become available.

Equations 23, 24, and 25 are divided into several simple parts to be used in the computer program. For example, "x" is set equal to $K_2 - K_1$ ($x = K_2 - K_1$) and "z" is set equal to 24 times the sludge load multiplied by the velocity of flow (z = 24 * SLOAD * VEL). (See page 66 and page 72.)

Simplifying the equations in this manner speeds up their solution by the computer and in many cases reduces the number of mathematical operations required, because once "x" or "z" is defined by appearing on the left-hand side of an arithmetic statement, it will retain its value until redefined. This allows recall of values for use in the solution of succeeding equations in which the same set of conditions applies.

DISCUSSION OF LOGIC USED IN COMPUTER PROGRAM

Discussion of Flow Diagram

The following is a narrative discussion of the basic flow diagram used in writing the computer program presented in this thesis and included in the Appendix. The definition of variables is also included in the Appendix. The boxes in the flow diagram, Figure 8, have been numbered, and these numbers will be used to indicate which bit of logic is being considered.

The reach numbering system used is designed so that the smallest reach number will be nearest the mouth of the river system, and the largest number at the uppermost point, as shown in Figure 9. Stepwise solution proceeds in accordance with the flow diagram as follows:

1. At this point all the data for each reach are read into core storage. These data include the reach number, stream order number, flow in the reach, physical data for the stream, temperature of the water, and all pertinent characteristics of the water and wastes entering the reach. The data are stored in a manner such

that any item may be recalled at any time by using coordinates of a two-dimensional array such as the one shown in Figure 7. As an example, the number 26 would be recalled by specifying coordinates (2, 2) and the number 31 would be recalled by the coordinates (1, 4).

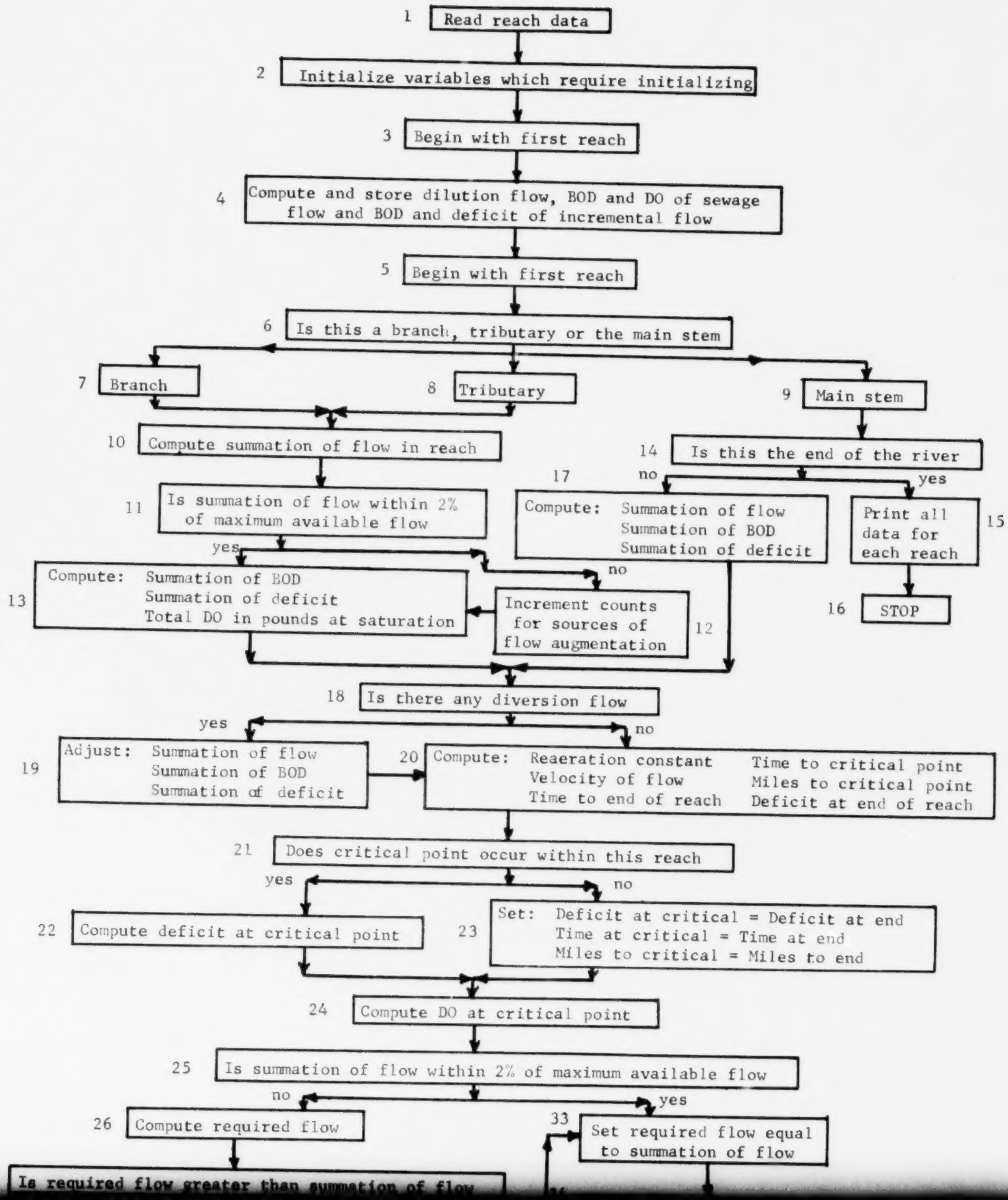
Column	1	2	3	4
Row 1	13	19	4	31
Row 2	8	26	3	16
Row 3	21	7	17	14

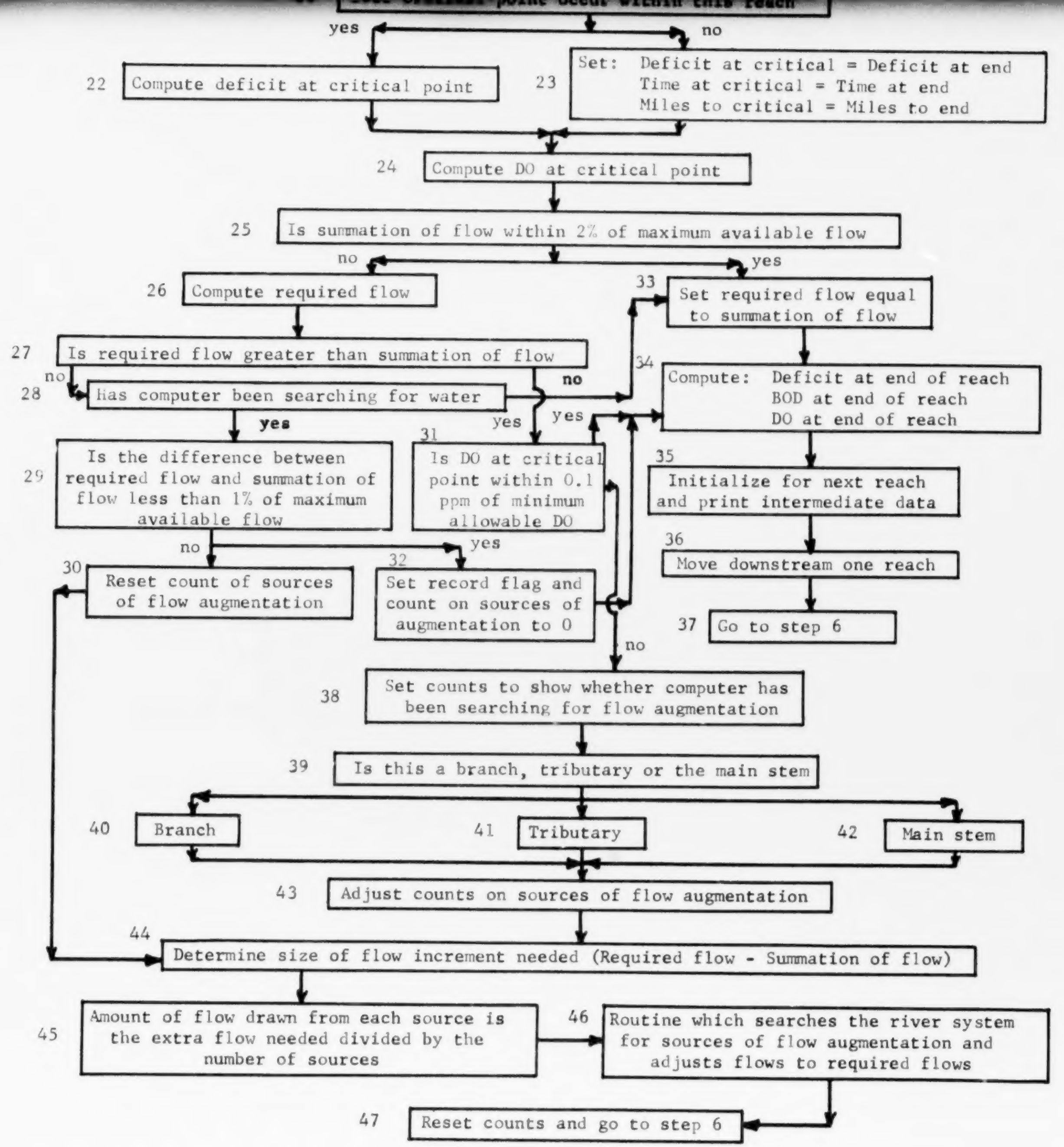
Figure 7. Simple array illustrating recall of data from core storage.

In this program the letter "I" is used as a general row number and set equal to a finite value of I = 1 at the start of the program. I is increased by an increment of 1 at the completion of computations for each reach, thereby causing the computer to proceed to the next reach. Columns are specified as exact numbers. A particular item could be recalled by specifying the co-ordinates, (I, 12).

All the data for one reach are stored on one row, which includes the number of columns necessary to contain the required data. In this program the array has a maximum dimension of 61 by 30, allowing for 60 rows of 30 columns each to describe each of 60 river reaches plus 1 row of data which tells the computer that it has completed the study. Any number of reaches from 1 through 60 may be used. Each reach will be described by 25 data read in at step 1 and five more items computed in step 4 will be included in the same array,

A


1 Read reach data
2 Initialize variables which require initializing
3 Begin with first reach
4 Compute and store dilution flow, BOD and DO of sewage flow and BOD and deficit of incremental flow
5 Begin with first reach
6 Is this a branch, tributary or the main stem
7 Branch
8 Tributary
9 Main stem
10 Compute summation of flow in reach
11 Is summation of flow within 2% of maximum available flow
yes
no
12 Increment counts for sources of flow augmentation
13 Compute: Summation of BOD
Summation of deficit
Total DO in pounds at saturation
14 Is this the end of the river
no
yes
15 Print all data for each reach
16 STOP
17 Compute: Summation of flow
Summation of BOD
Summation of deficit
18 Is there any diversion flow
yes
no
19 Adjust: Summation of flow
Summation of BOD
Summation of deficit
20 Compute: Reaeration constant
Velocity of flow
Time to end of reach
Time to critical point
Miles to critical point
Deficit at end of reach
21 Does critical point occur within this reach
yes
no
22 Compute deficit at critical point
23 Set: Deficit at critical = Deficit at end
Time at critical = Time at end
Miles to critical = Miles to end
24 Compute DO at critical point
25 Is summation of flow within 2% of maximum available flow
no
yes
26 Compute required flow
33 Set required flow equal to summation of flow
27 Is required flow greater than summation of flow
34


point occur within this reach
yes
no
22
Compute deficit at critical point
23
Set: Deficit at critical = Deficit at end
Time at critical = Time at end
Miles to critical = Miles to end
24
Compute DO at critical point
25
Is summation of flow within 2% of maximum available flow
no
yes
26
Compute required flow
33
Set required flow equal to summation of flow
27
Is required flow greater than summation of flow
no
28
Has computer been searching for water
no
34
Compute: Deficit at end of reach
BOD at end of reach
DO at end of reach
yes
yes
yes
31
Is DO at critical point within 0.1 ppm of minimum allowable DO
29
Is the difference between required flow and summation of flow less than 1% of maximum available flow
35
Initialize for next reach and print intermediate data
no
yes
36
Move downstream one reach
30
Reset count of sources of flow augmentation
32
Set record flag and count on sources of augmentation to 0
37
Go to step 6
no
38
Set counts to show whether computer has been searching for flow augmentation
39
Is this a branch, tributary or the main stem
40
Branch
41
Tributary
42
Main stem
43
Adjust counts on sources of flow augmentation
44
Determine size of flow increment needed (Required flow - Summation of flow)
45
Amount of flow drawn from each source is the extra flow needed divided by the number of sources
46
Routine which searches the river system for sources of flow augmentation and adjusts flows to required flows
47
Reset counts and go to step 6

B

FIGURE 8

SIMPLIFIED FLOW DIAGRAM

to make a total of 30 columns. The program could easily be expanded for a greater array of data to accommodate more detailed river systems by redefining TAB (the name of the array).

2. At this point it is necessary to define any variables which do not first appear on the left-hand side of an arithmetic statement. If a variable first appears on the left-hand side of an arithmetic statement, this will serve to define it and it need not be set equal to zero or other predetermined values at this point in the program. For example, "LINE = 26" would define "LINE" and "QUP = QBUP + QTUP" would define "QUP."

3. After all the data for each reach have been read into core storage and all variables have been defined or set for initial conditions, it is necessary to return to the first reach to begin computation.

4. In this step the computer uses some of the data stored in the array described in step 1 to compute several variables which will retain the same value throughout the program and each will be used several times in other computations. These values are stored in the last 5 columns of the array for future reference.

5. When the computations described in step 4 have been completed for each reach, it is necessary to return to the first reach to begin the dissolved oxygen analysis of the river system.

6. Step 6 is a routine for determining which order (branch, tributary, or main stem) of stream is represented by the reach under consideration.

7, 8, & 9. There are three possible answers (branch, tributary, or main stem) which could be obtained in step 6. These are used to indicate which of three routines will be followed in the next step. All three routines are similar, but do have important differences which must be taken into account.

10. In this routine, all components of flow entering the reach are added together to obtain a summation of flow or QSUM. This routine is similar for both branches and tributaries, but must be kept separate in order to obtain the proper summation of flows at confluences. Also, some different flow components are involved.

11. After total flow in a given reach is known, this value is compared with the maximum flow available in this reach. In this work, a variation of plus or minus 2% of the maximum available flow was assumed to be reasonable. Any other percentage could be used if conditions warranted. If the flow is more than 2% greater than the maximum available flow, the computer "pauses" or goes to a programmed "halt" and prints an error finding routine (see last line of long format output sheets) to help locate the error which caused the flow (QSUM) in the reach to be greater than the maximum available flow (QMAX).

12. If the flow (QSUM) in the reach is more than 2% less than the maximum available flow (QMAX), the counts (N_1 and N_2) of sources of flow augmentation are increased by one. The count N_2 is the number of sources on a particular tributary and N_1 is the total number of sources in the basin upstream from the reach under consideration.

13. After increasing N_1 and N_2 (step 12) or in the case in which the flow in the reach is within 2% of the maximum available flow, the computer determines the total BOD, the dissolved oxygen that would be in the water at saturation and the total deficit at the point under consideration. All parameters except flow are calculated and accumulated in pounds at this point in the program.

From step 13 the computer proceeds to step 18.

14. If the answer to step 6 had been "main stem," the computer would proceed to step 14 and decide whether this main stem reach is the last one on the river. This is determined by the information in column 1 in the array which contains the reach data. If the number in column 1 for this row or reach is a "0," this indicates that the last reach has been solved and that the system analysis has been completed.

15. If the last reach has been solved, the computer prints out all the prescribed data for each reach in the form of an array as shown on page 52.

16. When the list of data is completed, the computer "pauses" and is ready to receive the next program, or if there are no other programs the computer stops.

17. If the answer to step 6 is "main stem" but the last reach has not been solved, the computer goes through a routine similar to step 13 and determines the total flow in the reach, the total BOD, the dissolved oxygen that would be in the water if it were saturated and the total deficit that exists in the reach.

18. After completion of step 13 or step 17, the computer checks to see if any flow has been diverted from the reach.

19. In cases where flow has been diverted, a proportionate amount of BOD and deficit will be carried with it. This necessitates adjusting these values so that the proper loading will be considered in succeeding steps.

20. After adjustments are made (step 19) or if there was no diversion flow, the computer computes the reaeration constant (K_2), the velocity of forward flow in the river (VEL), the time (TIMEC) to the critical point in the reach, the distance in miles (CRMILE) to the critical point, the time (TEND) to the end of the reach and the deficit (DEND) at the end of the reach.

21. Next the computer determines whether the critical point falls somewhere within the reach.

22. If the critical point falls within the reach under consideration, the deficit at the critical point is computed.

23. If the critical point is outside the reach under consideration, the critical point in the reach is at one end. If the critical time approaches 0, the stream is recovering and the critical point in the reach is the upstream end. (In certain cases, it is possible to compute a negative deficit. This was assumed to be a non-existent situation so the deficit at the end of the reach is set to 0.) When the critical time exceeds the time to the end of the reach, the oxygen profile of the stream is still declining and the critical point is at the downstream end. In this case, the critical and end points

are the same and conditions at the critical point are set equal to those computed for the end of the reach.

24. Next the dissolved oxygen content at the critical point is computed in pounds and converted to parts per million (ppm) so that it may be compared with the minimum allowable dissolved oxygen in parts per million.

25. The function of this step is to determine whether water is available for flow augmentation in case the dissolved oxygen concentration at the critical point is less than the minimum allowable dissolved oxygen concentration.

26. At this point, the flow required to maintain the minimum dissolved oxygen content is computed. This computation is only an estimate due to the changes in reaeration constant and travel time which may result from the increase in flow. This would apply only to the case where flow augmentation is needed.

27. This step determines whether the flow required to maintain the minimum allowable dissolved oxygen content is greater than the flow presently in the reach. If the required flow is smaller than the flow present, the computer proceeds to step 28. If the required flow is larger than that present, the computer proceeds to step 31.

28. In the majority of cases, the computer will not have been searching for flow augmentation because the flow required to maintain minimum allowable dissolved oxygen content is less than the summation of flow in the reach. If there has been no searching for flow augmentation, the computer proceeds to step 33.

29. When the computer has been searching for flow augmentation, it is possible for the summation of flow to be larger than the required flow due to an over-estimate in step 26. This situation could result when the computer proceeded through steps 26, 27, 31, and 38 through 47 in that order and returned to step 6 to compute the conditions existing for the new flow. On this "run" to compute conditions for the new flow, the answer to step 28 would be "yes" and then step 29 is needed to determine the magnitude of the variation involved. If the answer to step 29 is "yes" the computer proceeds to step 32.

30. If the answer to step 29 is "no" it becomes necessary to "return" some of the flow to its original storage locations so the count on the number of sources of augmentation is reset to the value retained from the initial search. In this way an increment of flow can be "returned" to the same sources from which it was taken. After resetting the count (NHOLD=N=N_1 or N_2) to its original value, the computer proceeds to step 44.

31. Step 31 is a comparison between the dissolved oxygen content at the critical point and the minimum allowable dissolved oxygen, both in parts per million. Since an exact comparison is impractical on a digital computer, it was decided that the minimum allowable dissolved oxygen content plus or minus 0.1 part per million would be acceptable. Even though the required flow is greater than the summation of flow, no searching for flow augmentation would be done when the critical dissolved oxygen content was within 0.1 part

per million of the minimum allowable dissolved oxygen content. Extra flow would be sought when the 0.1 part per million limit was exceeded and the computer would proceed to step 38 to search for the necessary flow augmentation. The 0.1 ppm limit is for satisfying computer routine and should not be taken as a practical value for application.

32. A "yes" answer to step 29 would cause the computer to proceed to step 32 and set to 0 the count (NHOLD) which is used to indicate the number of sources from which water was originally taken and the count (LFLAG) which shows that the computer has been searching for flow augmentation. Step 34 follows step 32.

33. If the answer to step 25 is "yes," this means that no flow augmentation is available and the required flow cannot exceed the maximum flow available. In this case the required flow is set equal to the summation of flow which is within two percent of the maximum available flow.

34. At this point a flow which satisfies the minimum allowable dissolved oxygen content has been determined for the reach and the conditions at the end of the reach are computed. These are in parts per million for print out of data.

35. Here the computer resets to initial conditions certain variables to get ready to start the next reach and prints out some intermediate data.

36. Here the "I" mentioned in step one is increased by one and the next downstream reach is ready to be considered.

37. The computer returns to step 6 to begin the analysis of the new reach.

38. This step is used only when a search for flow augmentation is underway. The count (LFLAG) which indicates that the computer has been searching for extra flow is set to one in preparation for step 28 if needed. A zero indicates that no search has been made.

39. This is the same procedure as used in step 6 and its purpose is to determine which of the three orders of streams is being considered.

40, 41, & 42. These are the three possible answers to step 39 (branch, tributary or main stem) and are used to determine how the counts (N_1 and N_2) for sources of flow augmentation will be adjusted.

43. Here the counts (N_1 and N_2) are adjusted to determine from how many sources flow augmentation will be drawn.

44, 45. At this point the total amount of extra flow needed is computed and divided by the number of sources from which flow augmentation is available. This determines the amount of flow to be drawn from each source. The flow increment from each source may be either positive or negative depending on whether water is being "released" from storage or "returned" to storage. The negative increment would result in water being "returned" and would originate from an over-estimate of flow required in step 26 on the previous "run" through the analysis of this reach. The over-estimate would be detected in step 29 and the magnitude of the negative increment (-QEACH) would be determined in step 44.

46. The search for flow augmentation begins on the reach under consideration and works upstream one reach at a time until a source of extra flow is located. When a source of flow augmentation is located, the increment to be contributed by each source (QEACH) is added to the summation of flow in the reach on which extra flow was available. If more than one source is to contribute flow, the computer proceeds upstream one reach at a time until all sources have been tapped. These sources of flow augmentation are located only on the uppermost reach of any stream and normally extra flow would be available only below a reservoir. When all sources of extra flow have been utilized, the computer proceeds to the first reach in the system and resolves each reach for the new flow conditions.

47. This step resets the various counts (NHOLD, N, N_3) and resets to initial conditions pertinent variables in preparation for resolving the reach for the new flow conditions. This is accomplished by returning to step 6 and going through the program again.

Limitations and Restrictions

This program has the capacity to analyze a river system which includes one to three orders (main stem, tributary, or branch) of streams, including not more than 60 reaches which are defined as the stretch of river between two points at which a significant change occurs. Any number of reaches from one through sixty can be used. The program can be expanded easily for more detailed systems.

The reach numbering system, described below, must be organized so that the smallest reach number will be the reach nearest the mouth of the river system. Likewise, the largest number will be the most upstream reach and will be the first to be considered in analysis of the river system by the computer.

When the uppermost reach has been selected and given a number, the reaches are numbered in a downstream direction in descending order such that the second reach has a number smaller than the first, the third smaller than the second, etc. When a confluence is reached, the uppermost reach on the new stream will receive a number smaller than the number of the last reach of the stream just completed. The diagram in Figure 9 serves to illustrate the numbering system.

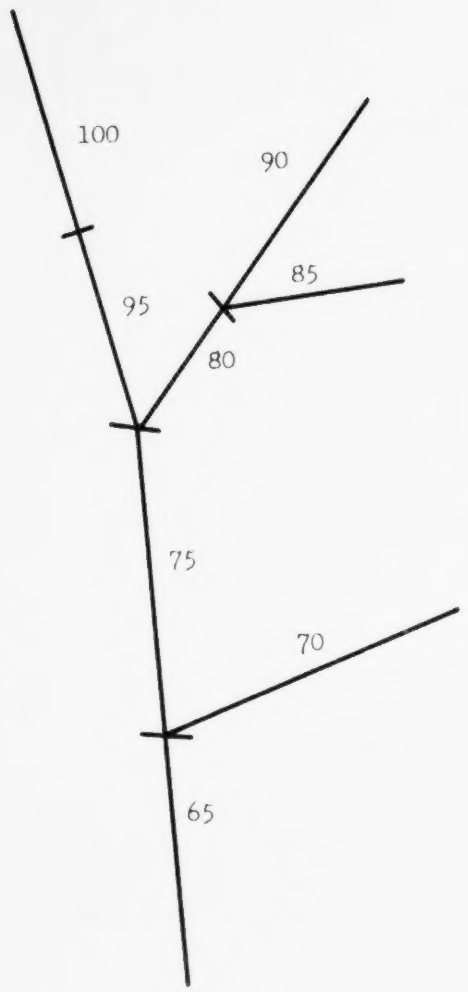


Figure 9. Simple river system to illustrate reach numbering system. See Limitations and Restrictions.

The reaches must be numbered in descending order in a downstream direction. It is advisable to leave gaps between the numbers so that new reaches can be inserted without disrupting the whole numbering system. The only restriction on the size of numbers used is that the largest cannot be larger than 999, and the smallest is one.

When analysis of the river system begins, the computer will start with the reach having the largest number (this is always a tributary reach) and proceed to the reach having the next smaller number. A reach number of zero is used to tell the computer when the last reach has been considered. Thus, the last data card must always contain a zero in the column for reach numbers.

The first reach or the reach having the largest number must always be designated as a tributary reach due to the way the program is written. This reach can be located anywhere in the river system so long as the reach numbering proceeds downstream in descending order from that point.

The uppermost reach on any particular stream starts at the most downstream reservoir on that stream or, in cases where reservoirs are absent, the uppermost reach would normally start at the farthest upstream point at which pollutional loading can be anticipated.

Each reach is identified on the data cards as being main stem, tributary, or branch by the numbers 3, 2, and 1, respectively. Numbering of reaches must be such that the computer would never proceed from branch to main stem or the reverse.

On reaches where no storage is available, the flows must be carefully checked to be sure the summation of the flow is within plus or minus two percent of the QMAX specified for that reach. If this restriction is not satisfied, a false source of flow augmentation is indicated to the computer.

In preparing data for this program it is necessary to determine relatively accurately the flow in each reach. This must be done for each level of flow to be considered in order to determine QMIN and QMAX for each reach.

In selecting reaches, the river system is divided into varying lengths in which a significant change occurs. Situations normally calling for the beginning of a new reach are: the confluence of two streams, the imposition of a significant waste load, or a decided change in slope or depth of the stream.

Reservoirs have not been included as reaches in this program because of a lack of data to determine velocities and reaeration rates. When data become available to determine the assimilation characteristics of reservoirs, they should be included as reaches in the river system. This would be especially useful in cases in which important waste loads are imposed upstream from a reservoir.

In cases in which reservoirs have turbulent spillways it may require introduction of a very short reach with a very high K_2 value to account for the reaeration which takes place over the spillway.

CONSIDERATIONS FOR APPLICATION TO A TYPICAL DRAINAGE BASIN

Description of Basin

The Willamette River system is located in northwestern Oregon and drains an area approximately 11,200 square miles in extent. The Willamette River Basin is oriented on a north - south axis at an approximate right angle to the lower main stem of the Columbia River. The river flows north to join the Columbia at Portland. The basin is roughly rectangular in shape with a north - south dimension of about 150 miles and an average width of about 75 miles. The Cascade Range, rising to elevations in excess of 10,000 feet, forms the eastern boundary and separates the Willamette and Deschutes River Basins. The Calapooya Mountains which rise to about 5,000 feet, form the southern boundary and separate the Willamette and Umpqua River Basins. On the west, the Coast Range rising to about 3,000 feet elevation separates the Willamette River Basin from the coastal drainage. The northern boundary separates the Willamette and Columbia River drainage and is formed by a range of low hills varying from 200 to 1,000 feet in elevation.

The Willamette River Basin is, in general, dish-shaped with the main valley floor located slightly west of center and foothills sloping up to rugged mountainous terrain on the east, south, and west boundaries. The Valley floor, comprised largely of rich agricultural land, is approximately 3,500 square miles in area and extends from above Eugene to the vicinity of Oregon City. The mean elevation of the valley floor is below 500 feet. A map of the river basin is shown in Figure 10.

The low water profile of the Willamette River upstream from Willamette Falls is typical of a stream with an unstable bed and consists of a series of relatively long, deep pools and short, steep bar crossings.

Flow Variations in the Basin

The Willamette River Basin is covered by a relatively complete network of U. S. Geological Survey gaging stations, and flow data obtained from these gaging stations are recorded in Part 14 of the U. S. Geological Survey Water-Supply Papers.

Table 3 lists some pertinent flow data for various stations on the main stem of the Willamette River and for one station on each of the major tributaries.

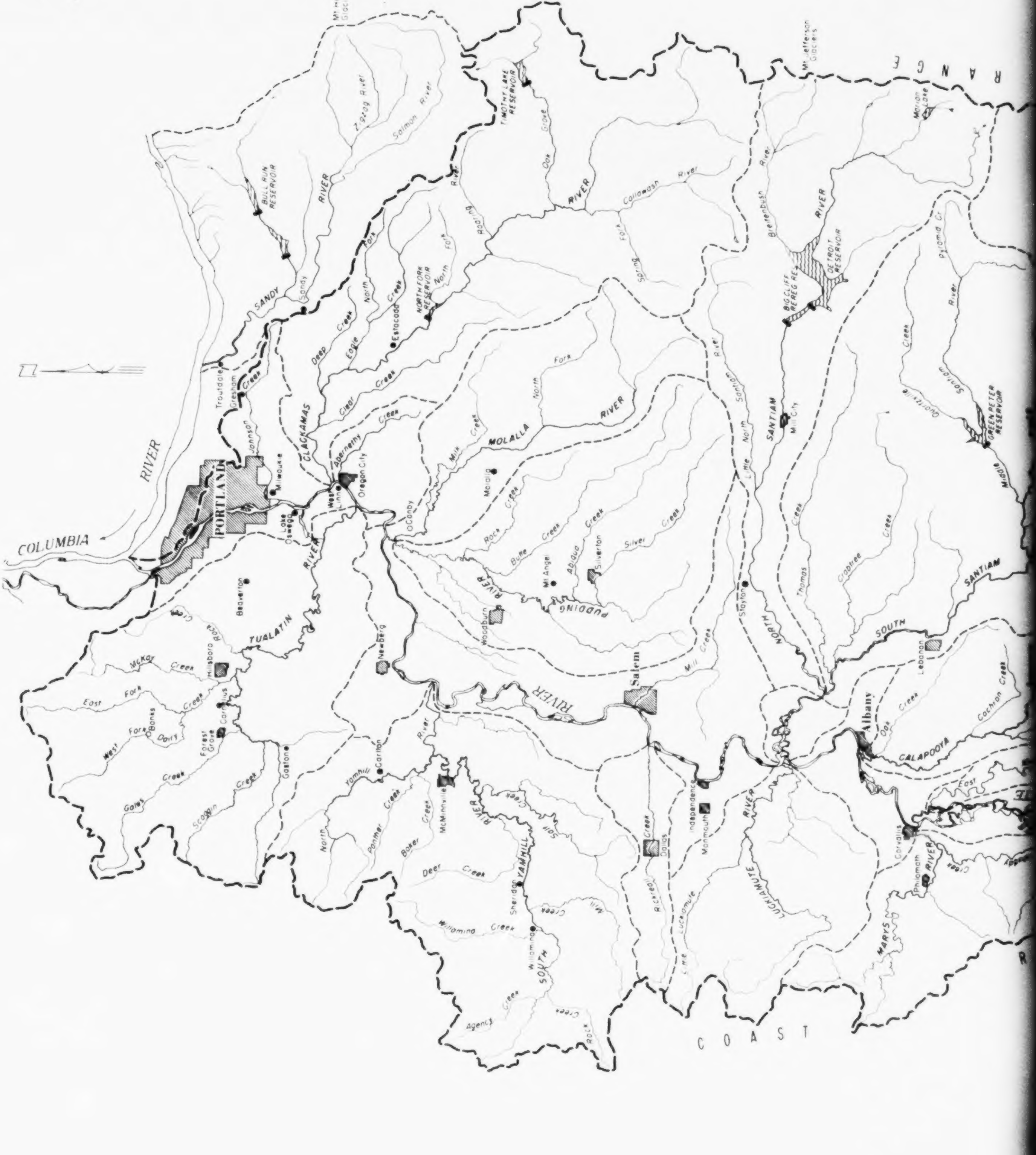
TABLE 3

Stream and Location of Station	Max. Flow of Record cfs	Av. Annual Flow cfs	Min. Flow of Record cfs	* Approx. Average Flow, cfs July	Aug.	Sept.
Willamette						
Salem	348,000	23,370	2,470	8,066	5,967	7,124
Albany	266,000	14,430	1,840	5,612	4,685	5,087
Harrisburg	210,000	12,840	1,990	5,054	4,325	4,347
Santiam						
Jefferson	161,000	7,838	260	1,952	943	1,822
McKenzie						
Coburg	88,200	6,081	1,250	2,942	2,219	2,103
Middle Fork Willamette						
Jasper	94,000	4,070	366	1,741	1,512	1,995
Coast Fork Willamette						
Goshen	58,500	1,760	36	353	743	462

---

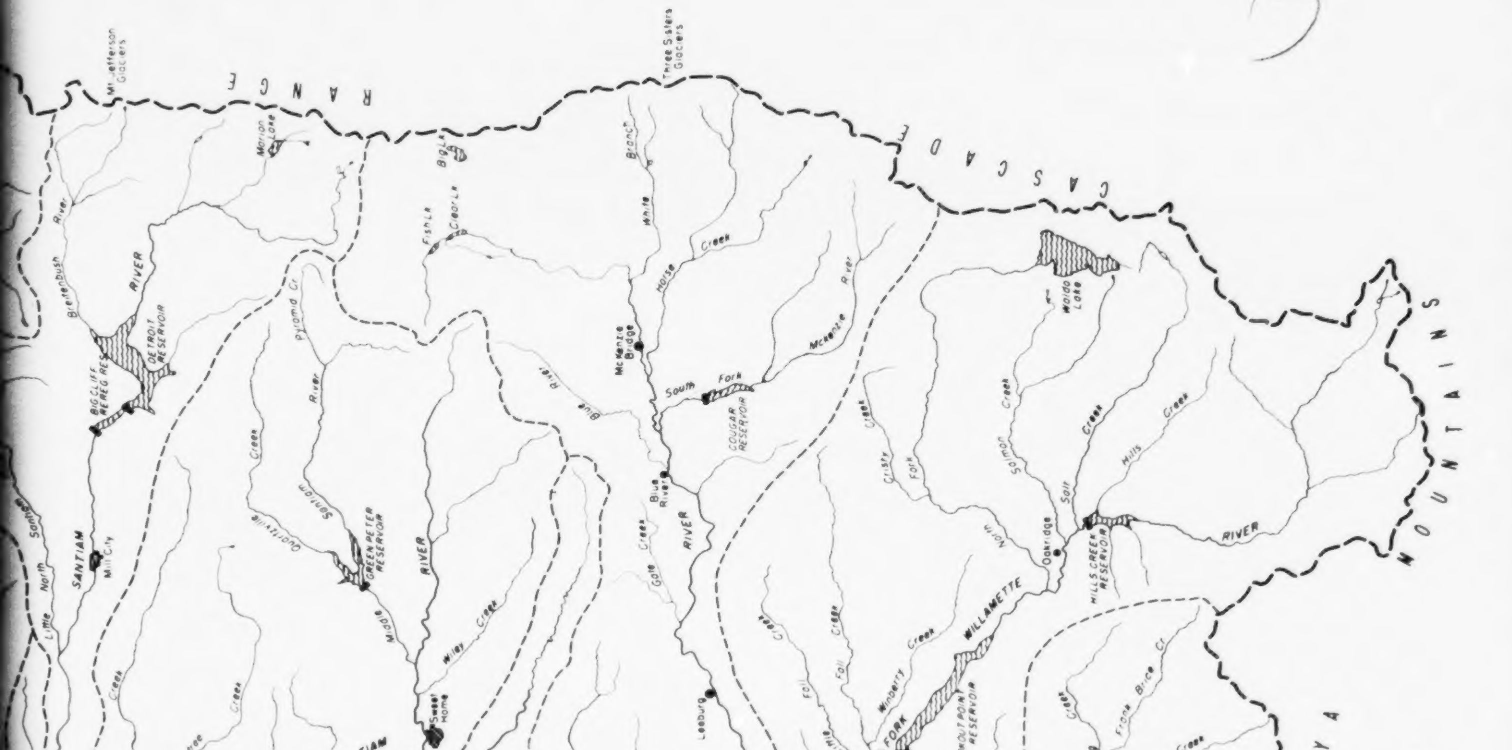
* Flows shown in the last three columns of Table 3 are an average of the mean flow for each month over the ten year period from 1952 through 1961. An exception is the Middle Fork Willamette River at Jasper, which is taken for the eight year period from 1954 through 1961.

A



Mt Hood Glaciers
Zigzag River
Salmon River
BULL RUN RESERVOIR
SANDY
RIVER
Sandy
Troutdale
Gresham
Johnson Creek
COLUMBIA
RIVER
PORTLAND
Milwaukie
Lake Oswego
West Linn
Oregon City
Abernethy Creek
CLACKAMAS
RIVER
Clear Creek
Deep Creek
Eagle Creek
North Fork
Estacada
NORTH FORK RESERVOIR
North Fork
Roaring River
TIMOTHY LAKE RESERVOIR
Oak Grove Fork
Collawash River
Spring
Breitenbush River
Mt Jefferson Glaciers
RANGE
Marion Lake
DETROIT RESERVOIR
BIG CLIFF REREG RES
Mill City
NORTH SANTIAM
Little North Santiam River
Stayton
Pyramid Cr
Quartzville Creek
GREEN PETER RESERVOIR
Middle
Santiam River
Thomas Creek
Crabtree Creek
SOUTH SANTIAM
Lebanon
Albany
Oak Creek
CALAPOOYA
Cochran Creek
East
Corvallis
Philomath
MARYS RIVER
MOLALLA RIVER
North Fork
Milk Creek
Molalla
Canby
Rock Creek
Butte Creek
Abiqua Creek
Mt Angel
Silverton
Silver Creek
PUDDING RIVER
Woodburn
Salem
Mill Creek
RIVER
Newberg
TUALATIN RIVER
Beaverton
Rock Creek
Hillsboro
McKay Creek
East Fork
Dairy Creek
West Fork
Banks
Cornelius
Forest Grove
Gales Creek
Scoggin Creek
Gaston
Carlton
Yamhill River
North Yamhill
Panther Creek
Baker Creek
McMinnville
RIVER
Deer Creek
YAMHILL
Sheridan
Salt Creek
Mill Creek
Willamina Creek
Willamina
SOUTH
Agency Creek
Rock Creek
COAST
Dallas
Rickreall Creek
Independence
Monmouth
LUCKIAMUTE RIVER
Little Luckiamute

B


Mt. Jefferson Glaciers
Three Sisters Glaciers
CASCADE RANGE
MOUNTAINS
CALAPOOYA
COAST RANGE
COAST
Marion Lake
Big Lake
Fish Lake
Clear Lake
Breitenbush River
RIVER
DETROIT RESERVOIR
BIG CLIFF REREG. RES.
Little North Santiam
NORTH SANTIAM
Mill City
Stayton
Thomas Creek
Crabtree Creek
Quartzville Creek
Pyramid Cr.
Sentiam River
GREEN PETER RESERVOIR
Middle River
Wiley Creek
Sweet Home
SOUTH SANTIAM
Lebanon
Albany
Oak Creek
Cochran Creek
CALAPOOYA
Brownsville
RIVER
Halsey
Muddy
Harrisburg
East
WILLAMETTE
Junction City
Monroe
RIVER
LONG TOM
Corvallis
Philomath
MARYS RIVER
Muddy Creek
West
LUCKIAMUTE RIVER
FERN RIDGE RESERVOIR
Veneta
Elmira
Spencer Cr.
Coyote Cr.
Eugene
Springfield
Coburg
Mohawk River
Marcola
McKENZIE
MIDDLE
Leaburg
Gate Creek
Blue River
Blue River
RIVER
McKenzie Bridge
South Fork
COUGAR RESERVOIR
McKenzie River
Horse Creek
White Branch
Lowell
DEXTER REREG. RESERVOIR
LOOKOUT POINT RESERVOIR
FORK
WILLAMETTE
Little Fall Creek
Fall Creek
Winberry Creek
North Fork
Christy Creek
Oakridge
Salmon Creek
Salt Creek
Hills Creek
HILLS CREEK RESERVOIR
RIVER
Waldo Lake
Lost Creek
Layng Creek
Brice Cr.
Sharps Creek
Row R.
DORENA RESERVOIR
Mosby Creek
COTTAGE GROVE RESERVOIR
Cottage Grove
WILLAMETTE
FORK
COAST
0 5 10 15
SCALE IN MILES

WILLAMETTE RIVER BASIN STUDY

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

Public Health Service, Pacific Northwest
Region IX, Portland, Oregon

Most of the flow data in Table 3 have been influenced to some extent by regulation of releases from reservoirs in the Basin. There are several reservoirs in operation at present and several more are either under construction or in planning stages. Table 4 lists the reservoirs which have been completed, are under construction, or have been authorized for construction in the Willamette River Basin and indicates their present state of development. Table 5 shows the location of the reservoirs on the streams, the drainage area above the reservoir and the various types and amounts of storage in each reservoir.

TABLE 4

Reservoir	Present Stage of Development	Stream
Cottage Grove	Operational 1942	Coast Fork Willamette River
Dorena	Operational 1949	Row River
Hills Creek	Operational 1961	Middle Fork Willamette River
Lookout Point	Operational 1954	Middle Fork Willamette River
Dexter (Rereg)	Operational 1954	Middle Fork Willamette River
Fall Creek	Under Construction	Fall Creek
Cougar	Under Construction	South Fork McKenzie River
Strube (Rereg)	Authorized	South Fork McKenzie River
Blue River	Under Construction	Blue River
Gate Creek	Authorized	Gate Creek
Fern Ridge	Operational 1941	Long Tom River
Holley	Authorized	Calapooya River
Cascadia	Authorized	South Santiam River
Green Peter	Under Construction	Middle Santiam River
Foster (Rereg)	Under Construction	South Santiam River
Detroit	Operational 1953	North Santiam River
Big Cliff	Operational 1953	North Santiam River
Fern Ridge (Modification)	Authorized	Long Tom River

TABLE 5

Reservoir	Stream Mile	Drainage Area sq. mile	Proposed Storage--acre feet			
			Flood Control	Dead	Power	Total
Cottage Grove	28.0	104	30,000	3,000	--	33,000
Dorena	7.0	265	70,000	6,000	--	76,000
Hills Creek	47.8	389	200,000	59,000	21,000	280,000
Lookout Point	21.3	991	340,000	88,000	28,000	456,000
Dexter (Rereg)	18.0	996	--	23,850	3,650	27,500
Fall Creek	7.1	184	115,000	10,000	--	125,000
Cougar	4.4	210	155,000	28,000	27,000	210,000
Strube (Rereg)	2.5	216	--	2,900	3,000	5,900
Blue River	0.6	88	85,000	5,000	--	90,000
Gate Creek	0.4	50	50,000	5,000	--	55,000
Fern Ridge	23.6	275	110,000	7,000	--	117,000
Holley	49.7	99	90,000	7,000	--	97,000
Cascadia	59.8	179	145,000	15,000	--	160,000
Green Peter	4.0	277	270,000	38,000	52,000	360,000
Foster (Rereg)	38.5	494	30,000	27,400	3,600	61,000
Detroit	48.5	438	300,000	115,000	40,000	455,000
Big Cliff	45.7	450	--	1,950	1,800	3,750
Fern Ridge (Modification)	23.6	275	15,000	--	--	15,000

When all the reservoirs listed in Tables 4 and 5 have been completed, it should be possible by controlling releases from storage, to maintain the flow in the Willamette River system throughout the year at levels desired by water management agencies. This relatively large amount of storage should provide adequate water for use in low flow augmentation for pollution abatement at nearly any point in the basin.

Economic Development of Basin

The Willamette River Basin had a population of 1,169,000 in 1960 of which more than half is concentrated in and near Portland in the lower end of the basin.

The economy of the Willamette River Basin is largely dependent on timber-based manufacturing, agriculture, and food processing. However, light metal industries, electronics industries and other diversified manufacturing along with service industries are becoming important contributors to the economy of the area.

The potential growth of the basin is expected to develop around the existing economic base activities.

Effective Pollutional Load in Basin

Current estimates of municipal and industrial waste production in the Willamette River Basin place the raw waste population equivalent at about 5.25 million. Most of these wastes receive some form of treatment which results in removal or satisfaction of about two-thirds of the BOD. The population equivalent of the treated wastes discharged into the streams of the basin is about 1.7 million.

Waste production by 1985 and 2010 is expected to increase by approximate factors of 1.3 and 1.9, respectively. Increases of this order in waste loadings during coming years will almost certainly cause a definite hazard to the oxygen resources of the streams in the basin during periods of low flow.

Increased use of irrigation in the Willamette River Basin can be expected in coming years. This will tend to increase the pollutional load in the river system in several ways. First, the use of more water in the fields will decrease the flow in the river unless releases from storage offset the extra draft. Also, there will be more irrigation return flow carrying insecticides, nutrients, and various other contaminants into the river. Probably the most important pollution problem created by more extensive use of irrigation will be an indirect one due to an expansion in the food processing industries. Such an expansion can be expected because irrigation will result in an increase in the acreage utilized for cannery crops and will increase yields from land now in production.

The digital computer program presented in this thesis can be used to predict the conditions which would exist under the future loadings described above and provide data to be used in reaching decisions on water resource management problems. Various loading situations and levels of flow can be tried to determine the most economical combination of treatment and flow augmentation. Computer output data for a single loading and a fixed level of flow is shown in the next section. Output data from a model river system is also shown to demonstrate the ability of the computer program to search for flow augmentation and adjust the flow to maintain a minimum allowable dissolved oxygen concentration. This latter analysis was performed on the model basin to test all features of the program which were not utilized by the Willamette River because of waste discharge-flow relations.

RESULTS AND OUTPUT DATA

Explanation of Output Data Sheets

This computer program incorporates two different output formats resulting in a short output data sheet of five columns and a long output data sheet of fifteen columns.

The short format (see page 51) is printed at the completion of the analysis of each reach and includes the reach number (RENO), the stream order number (DIGIT), the flow (QDUP) necessary to satisfy minimum dissolved oxygen requirements for this reach considering only upstream loadings, the velocity of flow (VEL) and the dissolved oxygen concentration at the critical point in the reach (DOCPPM). The purpose of this format is to show the flow, velocity and critical dissolved oxygen content in each reach the first time it is analyzed and to show the magnitude of flow increments used in adjusting flows to satisfy minimum requirements when necessary to search for flow augmentation. If no change in flow can be effected for a particular reach, the output data for that reach will be repeated exactly as it was printed the first time the reach was analyzed. In cases where flow augmentation is available, the size of increment needed is shown along with the effect of the change in flow on the critical dissolved oxygen content. For any reach, the difference between QDUP the first time it appears and the last time it appears will be the amount of extra flow which must be carried in the reach in order to satisfy downstream minimum dissolved oxygen requirements. The last time QDUP appears for any reach, it should be the same as the flow (QSUM in the long output format) necessary to meet minimum dissolved oxygen requirements, considering the whole river system and all loads imposed throughout the basin.

As an example, on the third row of data on page 51, the reach number (RENO) is 101, the stream order number (DIGIT) is 2, which indicates a tributary, the flow (QDUP) to satisfy minimum requirements for this reach considering only upstream loads is 922 cfs, the velocity of flow (VEL) in the river is 1.59 miles per hour and the dissolved oxygen content at the critical point (DOCPPM) is 10.48 ppm.

The data printed by the long output format describes the conditions which exist in the river system after it has been completely analyzed and the flows adjusted to satisfy all minimum requirements or all applicable sources of flow augmentation are exhausted. Explanation of column headings for the long format output data sheet can be found on pages 61 through 66.

The following pages are examples of output data printed by both formats and serve to illustrate the reason for having two output formats.

MODEL RIVER SYSTEM
SHORT FORMAT
OUTPUT DATA SHEET

RENO	DIGIT	QDUP	VEL	DOCPPM
105.	2.	1001.	1.59	10.48
103.	1.	40.	1.59	10.47
101.	2.	992.	1.59	10.48
96.	2.	551.	.72	9.48
95.	2.	651.	.77	1.87
105.	2.	1135.	1.59	10.49
103.	1.	40.	1.59	10.47
101.	2.	1056.	1.59	10.48
96.	2.	551.	.72	9.48
95.	2.	651.	.77	1.87
89.	3.	1738.	.93	7.03
105.	2.	1310.	1.59	10.49
103.	1.	40.	1.59	10.47
101.	2.	1232.	1.59	10.48
96.	2.	551.	.72	9.48
95.	2.	651.	.77	1.87
89.	3.	1914.	.98	7.35
88.	3.	1945.	.99	7.20
105.	2.	1760.	1.59	10.49
103.	1.	40.	1.59	10.47
101.	2.	1681.	1.59	10.49
96.	2.	551.	.72	9.48
95.	2.	651.	.77	1.87
89.	3.	2363.	1.10	7.95
88.	3.	2394.	1.11	7.75
87.	3.	2425.	1.12	7.77
86.	3.	2456.	1.13	7.84
85.	3.	2487.	1.14	8.04

LONG FORMAT OUTPUT DATA FOR MODEL RIVER SYSTEM

```
RENO   DIGIT   QSUM   DOCPPM   DCP   DOEND   DENDPM   BODEND   TIMEC   TEND   CRMILE   RELEN   RIVMI   REK2      TEMP
105.    2.     1760.   10.49   0.00  10.49   0.00       0.0    0.000   .182    0.0       7.0    18.0   4.18341   13.4
103.    1.       40.   10.47    .02  10.49   0.00       0.0    0.000   .187    0.0       7.2     7.2   8.67636   13.4
101.    2.     1681.   10.49   0.00  10.49   0.00       0.0    0.000   .286    0.0      11.0    11.0   4.18341   13.4
 96.    2.      551.    9.48    .01   9.49   0.00       0.0    0.000   .462    0.0       8.0    28.0   5.85816   18.0
 95.    2.      651.    1.87   7.62   4.02   5.47      30.9     .423  1.071    7.9      20.0    20.0   4.95033   18.0
 89.    3.     2363.    7.95   2.04   7.95   2.04       6.9     .412   .412   11.0      11.0   187.0   1.18030   16.0
 88.    3.     2394.    7.75   2.24   7.75   2.24       5.5     .409   .409   11.0      11.0   176.0   1.17948   16.0
 87.    3.     2425.    7.77   2.22   7.82   2.17       4.4     .096   .406    2.6      11.0   165.0   1.17868   16.0
 86.    3.     2456.    7.84   2.15   8.02   1.97       3.6    0.000   .403    0.0      11.0   154.0   1.17788   16.0
 85.    3.     2487.    8.04   1.95   8.26   1.73       2.9    0.000   .400    0.0      11.0   143.0   1.17709   16.0

       RENO   HUNT   DIGIT   TIMEC   DOCPPM   KNT   KOUNT   N1   N2   N3   N4   LFLAG   QREQD   QOVER   QSUM
       105.   87.    2.      0.000   10.494   1     2       0    0    0    0    1       1760.   1807.   1760.
```

WILLAMETTE RIVER SYSTEM SHORT FORMAT OUTPUT DATA SHEET

RENO	DIGIT	QDUP	VEL	DOCPPM
105.	2.	1760.	1.59	9.49
103.	1.	40.	2.72	9.57
101.	2.	1680.	1.59	10.00
99.	2.	650.	1.74	8.59
97.	1.	135.	1.16	8.59
96.	2.	801.	.85	9.33
95.	2.	811.	.86	9.45
93.	3.	2491.	1.14	10.04
91.	3.	2521.	1.15	9.98
89.	3.	2541.	1.11	9.86
85.	2.	1445.	4.08	9.99
81.	2.	1680.	1.53	9.99
79.	2.	1790.	1.49	9.99
77.	2.	1840.	1.36	9.70
75.	3.	4381.	2.10	9.50
73.	3.	4502.	2.13	9.35
71.	2.	35.	.51	8.32
70.	2.	35.	.34	8.79
69.	3.	4612.	1.47	9.26
67.	2.	20.	.51	8.22
65.	3.	4703.	1.69	9.13
64.	2.	30.	2.04	8.70
63.	2.	30.	1.02	9.14
62.	2.	30.	.68	9.15
61.	3.	4802.	1.53	9.02
59.	2.	1230.	4.08	10.27
57.	2.	1330.	3.40	10.00
55.	1.	180.	1.90	8.82
54.	1.	60.	.48	9.21
53.	1.	74.	.48	7.50
51.	2.	724.	1.53	9.74
47.	3.	5602.	1.76	9.05
43.	3.	5901.	1.84	8.81
39.	2.	40.	.34	7.86
37.	3.	5961.	1.43	8.72
35.	3.	6111.	.33	7.62
33.	2.	20.	1.63	5.13
32.	2.	30.	1.63	5.07
31.	3.	6222.	.43	7.42
29.	2.	10.	.20	7.47
27.	2.	15.	.20	5.56
26.	2.	35.	.20	5.03
25.	2.	44.	.20	5.35
23.	2.	25.	.20	5.66
21.	3.	6247.	.43	7.36

LONG FORMAT OUTPUT DATA FOR WILLAMETTE RIVER SYSTEM

RENO	DIGIT	QSUM	DOCPPM	DCP	DOEND	DENDPM	BODEND	TIMEC	TEND	CRMILE	RELEN	RIVMI	REK2	TEMP
105.	2.	1760.	9.49	1.00	10.01	.48	.5	0.000	.182	0.0	7.0	18.0	4.18341	13.4
103.	1.	40.	9.57	.92	10.14	.35	0.0	0.000	.110	0.0	7.2	7.2	8.67636	13.4
101.	2.	1680.	10.00	.49	10.32	.17	.5	0.000	.286	0.0	11.0	11.0	4.18341	13.4
99.	2.	650.	8.59	.90	9.34	.15	.4	0.000	.167	0.0	7.0	7.0	11.22660	18.0
97.	1.	135.	8.59	.90	9.43	.06	.4	0.000	.287	0.0	8.0	28.0	10.11780	18.0
96.	2.	801.	9.33	.16	9.46	.03	.4	0.000	.584	0.0	12.0	20.0	5.85816	18.0
95.	2.	811.	9.45	.04	9.46	.03	.4	0.000	.387	0.0	8.0	8.0	4.95033	18.0
93.	3.	2491.	10.04	.15	10.04	.15	.5	0.000	.072	0.0	2.0	187.0	1.17698	15.0
91.	3.	2521.	9.98	.01	9.98	.01	.5	.180	.180	5.0	5.0	185.0	1.17623	16.0
89.	3.	2541.	9.86	.03	9.86	.03	1.4	.149	.149	4.0	4.0	180.0	.86203	16.6
85.	2.	1445.	9.99	0.00	9.99	0.00	0.0	.030	.030	3.0	3.0	56.0	11.09724	16.0
81.	2.	1680.	9.99	0.00	9.99	0.00	0.0	.408	.408	15.0	15.0	53.0	3.46500	16.0
79.	2.	1790.	9.99	0.00	9.99	0.00	0.0	.779	.779	28.0	28.0	38.0	3.11688	16.0
77.	2.	1840.	9.70	0.00	9.69	0.00	.3	.306	.306	10.0	10.0	10.0	2.20228	17.0
75.	3.	4381.	9.50	0.00	9.49	0.00	.9	.237	.237	12.0	12.0	176.0	1.28694	18.0
73.	3.	4502.	9.35	.04	9.35	.04	.8	.409	.409	21.0	21.0	164.0	1.28472	18.5
71.	2.	35.	8.32	.57	8.81	.08	.9	0.000	1.029	0.0	12.6	23.6	4.46985	21.5
70.	2.	35.	8.79	.10	8.82	.07	.8	0.000	1.347	0.0	11.0	11.0	4.46985	21.5
69.	3.	4612.	9.26	.03	9.26	.03	.7	.225	.225	8.0	8.0	143.0	.93786	19.5
67.	2.	20.	8.22	.77	8.85	.14	1.7	0.000	.612	0.0	7.5	7.5	5.30838	21.0

RENO	DIGIT	QSUM	DOCPPM	DCP	DOEND	DENDPM	BODEND	TIMEC	TEND	CRMILE	RELEN	RIVMI	REK2	TEMP
65.	3.	4703.	9.13	.16	9.13	.16	1.2	.369	.369	15.0	15.0	135.0	1.41510	19.5
64.	2.	30.	8.70	.50	9.14	.05	.2	0.000	.204	0.0	10.0	50.0	12.01200	20.0
63.	2.	30.	9.14	.05	9.19	0.00	.2	0.000	.408	0.0	10.0	40.0	9.27072	20.0
62.	2.	30.	9.15	.04	9.17	.02	.4	0.000	1.837	0.0	30.0	30.0	6.85030	20.0
61.	3.	4802.	9.02	.17	9.02	.17	1.3	.298	.298	11.0	11.0	120.0	1.27046	20.0
59.	2.	1230.	10.27	.52	10.60	.19	.4	0.000	.212	0.0	20.8	45.8	5.10579	12.0
57.	2.	1330.	10.00	0.00	10.00	0.00	.4	.306	.306	25.0	25.0	25.0	4.43242	16.0
55.	1.	180.	8.82	.57	9.21	.18	1.0	0.000	.273	0.0	12.5	27.5	5.36451	19.0
54.	1.	60.	9.21	.18	9.30	.09	.9	0.000	.255	0.0	3.0	15.0	5.08200	19.0
53.	1.	74.	7.50	1.69	7.85	1.34	19.8	.104	1.020	1.2	12.0	12.0	5.08200	20.0
51.	2.	724.	9.74	.05	9.74	.05	1.3	.299	.299	11.0	11.0	11.0	3.35643	16.5
47.	3.	5602.	9.05	.24	9.05	.24	1.0	.591	.591	25.0	25.0	109.0	1.40927	19.5
43.	3.	5901.	8.81	.38	8.81	.38	1.8	.655	.655	29.0	29.0	84.0	1.38613	20.0
39.	2.	40.	7.86	.93	7.88	.91	2.0	.913	1.347	7.4	11.0	11.0	.87549	22.0
37.	3.	5961.	8.72	.27	8.72	.27	1.7	.145	.145	5.0	5.0	55.0	.49425	21.0
35.	3.	6111.	7.62	1.27	7.62	1.27	1.4	1.744	1.744	14.0	14.0	50.0	.09430	21.5
33.	2.	20.	5.13	4.06	5.13	4.06	24.1	.382	.382	15.0	15.0	26.0	.34650	20.0
32.	2.	30.	5.07	4.12	5.07	4.12	15.8	.280	.280	11.0	11.0	11.0	.34650	20.0
31.	3.	6222.	7.42	1.47	7.42	1.47	1.2	.671	.671	7.0	7.0	36.0	.14073	21.5
29.	2.	10.	7.47	1.32	7.51	1.28	.7	1.715	2.654	8.4	13.0	59.0	.27720	22.0

```
RENO   DIGIT   QSUM   DOCPPM   DCP    DOEND   DENDPM   BODEND   TIMEC   TEND   CRMILE   RELEN   RIVMI    REK2     TEMP
 27.     2.     15.     5.56   3.23    5.56    3.23      3.9    1.429   1.429     7.0     7.0    46.0   .27720    22.0
 26.     2.     35.     5.03   3.76    5.05    3.74      2.6    1.957   2.245     9.5    11.0    39.0   .27720    22.0
 25.     2.     44.     5.35   3.44    6.37    2.42       .8     .989   4.491     4.8    22.0    28.0   .27720    22.0
 23.     2.     25.     5.66   3.13    5.66    3.13      2.3    1.118   1.225     5.4     6.0     6.0   .27720    22.0
 21.     3.   6247.     7.36   1.53    7.36    1.53      1.1     .286    .286     3.0     3.0    29.0   .14089    21.5

         RENO   HUNT   DIGIT   TIMEC   DOCPPM   KNT   KOUNT   N1   N2   N3   N4   LFLAG   QREQD   QOVER   QSUM
         105.     0.     2.    0.000    9.498    1      2     0    0    0    0      0    1760.      0.   1760.
```

CONCLUSIONS

1. A digital computer can be readily adapted to the solution of the Streeter-Phelps oxygen sag equations and can apply the results of such solutions to the determination and adjustment of flows required to maintain a minimum allowable dissolved oxygen concentration in streams.

2. This digital computer program can provide in a few minutes, data which would normally require many man hours of hand computations. Such data can be applied to provide answers to water management problems that would otherwise be hindered by the massive computations involved.

3. Management decisions on future water use must be based upon maximum benefits which can be obtained from the existing water resources. Such decisions must be predicated upon a knowledge of the results of water utilization practices. Prudent judgment demands that all possible uses be considered. An analysis of this magnitude is beyond the limited manpower capabilities at the present time and can be significantly aided by application of digital computer techniques.

4. Many types of studies are needed for water management. The program presented can be adapted to the analysis of various water quality perameters and can possibly provide a basis of solution for some of the problems that exist regarding waste treatment, flow augmentation and planned development based upon resource.

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APPENDIX

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Note: (1) Necessary equations may be found on Pages 9 thru 25 of the main paper.

(2) A detailed flow chart or logic diagram may be found in pocket inside back cover.

Explanation of Variables Used in Program

A	e^{-K_1} TEND.
AA	Z/K_2.
AK2	Coefficient of Q in $K_2 = aQ^b$.
B	e^{-K_2} TEND.
BB	ZSL/K_2.
BK2	Exponent of Q in $K_2 = aQ^b$.
BKLOD	Bank load, pounds/mile/day. This is the uniform load which is assumed to be exerted along the banks of any stream. Might also include load exerted by algae die-off. (This last item might be included as SLOAD.)
BOD	Biochemical oxygen demand.
BODBU	BOD of branch reach immediately upstream in total pounds.
BODD	BOD of dilution flow (QDIL) in ppm.
BODDP	BOD of dilution flow (QDIL) in total pounds.
BODEND	BOD at end of reach, ppm.
BODI	BOD of incremental flow (QI), ppm.
BODIP	BOD of incremental flow, total pounds.
BODMU	BOD of main stem reach immediately upstream in total pounds.
BODNDP	BOD at end of reach in total pounds.
BODS	BOD of sewage, ppm.
BODSP	BOD of sewage, total pounds.
BODTU	BOD of tributary reach immediately upstream in total pounds.
BODTUT	BOD in first of two tributaries in the case where two tributaries come together. Replaces BODTU for this specific case.
C	$(K_1 SUMBOD/X)(A - B)$.

C1	K_1 (SUMBOD).
CC	e^{-K_1} TIMEC.
CC1	K_1 (CC) (SUMBOD).
cfs	Cubic feet per second.
CRMILE	Miles to critical point from head of reach.
CVEL	Coefficient of Q in $V = cQ^d$.
DCLBS	Critical deficit, total pounds.
DCPPM	Critical deficit, ppm.
DD	Deficit of dilution water (QDIL), ppm.
DDP	Deficit of dilution water, total pounds.
DEFSUM	Summation of all the deficits within the reach, total pounds. DEFSUM = (DOSAP - DOTUP - DOBUP - DOSP) + DIP + DDP.
DELTAQ	QREQD - QSUM. This is the estimated extra flow (cfs) needed to satisfy DOMIN requirements.
DEND	Deficit at end of reach, total pounds.
DI	Deficit of incremental flow (QI), ppm.
DENDPM	Deficit at end of reach in ppm.
DIGIT	An identification number or stream order number. (1) for branches; (2) for tributaries; and (3) for main stem.
DIP	Deficit of incremental flow, total pounds.
DO	Dissolved oxygen.
DOBUP	DO in branch reach immediately upstream in total pounds.
DOCLBS	Critical DO in total pounds.
DOCPPM	Critical DO in ppm.
DOEND	DO at end of reach, ppm.
DOENDP	DO at end of reach, total pounds.
DOMIN	Minimum desired dissolved oxygen, ppm, in any reach.

DOMUP	DO in main stem reach immediately upstream in total pounds.
DOS	DO of sewage flow, ppm.
DOSAP	Dissolved oxygen, at saturation total pounds per day in any reach.
DOSAT	Dissolved oxygen, ppm, at saturation in water in any reach.
DOSP	DO of sewage (QS) in total pounds.
DOTUP	DO in tributary reach immediately upstream in total pounds.
DOTUPT	DO in first of two tributaries in the case where two tributaries come together. Replaces DOTUP for this specific case.
DOXKI	Deoxygenation constant K_1 (base e). Units of 1/days.
DVEL	Exponent of Q in $V = cQ^d$.
E	e = 2.71828 = base of natural or Naperian logs.
F	K_2 (1 - A).
FNUM	The count N changed from fixed point to floating point notation (FNUM = N).
G	K_1 (1 - B).
HUNTER	A device used to tell when the computer has returned to the original reach where the flow was insufficient to maintain DOMIN. Will be used only when computer has been looking for extra flow.
K	The number of reaches in a particular river system.
KNT	A count used to indicate the case where two tributaries come together.
KOUNT	A count used to tell the computer when computations for the last reach have been completed.
LFLAG	Record flag. This is an index to show whether computer has been looking for extra water.
LINE	The number of lines of printing on the output sheets.
N	Replaces N_1 or N_2 when looking for flow augmentation.

N_1	Number of sources of flow augmentation in entire basin.
N_2	Number of sources of flow augmentation on any tributary (the one being considered).
N_3	Used to keep track of sources used as compared to sources available. N_3 is incremented by 1 each time a source is tapped and when $N_3 = N$, all sources have been used.
N_4	Number of sources of flow augmentation on the second tributary in the case where two tributaries come together to form the main stem.
NHOLD	A device for retaining the value of N after a QEACH has been calculated. Needed for the case where QEACH is too large.
ppm	Parts per million = mg/L = milligrams per liter.
Q	Flow in cfs.
Q539	5.39 (QSUM).
QBUP	Flow (cfs) in the branch reach immediately upstream from the one under consideration. In the case of the uppermost reach, by definition, there is no reach above it and, therefore, QBUP = 0. In this case, QMIN = QDIL will have a value. For reaches below uppermost reach, QBUP has a value and QMIN and QDIL = 0.
QDIL	Dilution flow, cfs.
QDUP	The flow (cfs) required to solve this reach considering only reaches upstream from this point.
QEACH	DELTAQ/N. This is the flow (cfs) that would be taken from each source of flow augmentation.
QI	Incremental flow, cfs. This flow is made up of ground water, small creeks and other flow which cannot be accounted for at the end of each reach.
QMAX	Maximum flow to be considered in any given reach, cfs. This flow will be the greatest flow which might be reasonably provided to assimilate wastes which are discharged into the streams of the basin. QMAX will vary for each reach.

QMIN	Minimum flow in any given reach, cfs. Normally, 0 for all but uppermost reach on each tributary or branch. This is by definition and is done to aid in searching for reaches where supplemental flow is available.
QMUP	Flow (cfs) in main stem reach immediately upstream from reach being considered. Same explanation as above for QBUP applies here.
QOUT	Diversion flow, cfs. This is the flow taken out of the river for irrigation or other purposes.
QOVER	Replaces QREQD when QREQD exceeds QMAX. Used as a device to keep track of extra flow (cfs) in case some was not needed. (When estimated QREQD was greater than actually needed.)
QREQD	Flow (cfs) needed to maintain DOMIN in the reach with the loads exerted.
QS	Flow of sewage or industrial waste, cfs.
QSUM	Summation of Q in the reach, cfs. QUP + QS + QDIL + QI (etc.)
QSUMP	Summation of Q for case where QOUT is not 0. QSUMP = QSUM - QOUT.
QTUP	Flow (cfs) in tributary reach immediately upstream from the one being considered. Same explanation as above for QBUP applies.
QTUPT	The flow in the first of two tributaries in the case where two tributaries come together. Replaces QTUP for this specific case.
QUP	QBUP + QTUP, cfs.
RATIO	QSUMP/QSUM.
REK2	Reaeration constant, k_2 (base 10), converted to base e within program. Units of 1/days.
RELEN	Reach length, miles.
RENO	Reach number.
RIVMI	The river mile to the head of each reach from mouth of the stream on which this particular reach happens to be.

SLOAD	Sludge load, pounds/mile/day, exerted by sludge deposits within any reach.
SUMBOD	Summation of BOD, total pounds. SUMBOD = BODBU + BODTU + BODSP + BODIP + BODD + BODMU.
TAB	An abbreviation used to designate the array or table which contains all the reach data.
TEMP	Temperature in any reach, °C.
TEND	Time to end of reach, days.
TIMEC	Time to critical point in sag curve, days.
U	K_1^2 SUMBOD - $K_1 Z$.
VEL	Velocity of flow (ft/sec), converted to miles per hour in program before used in any computations.
W	Y(SUMBOD) + X(ZSL - K_2 DEFSUM) - $K_1 Z$.
X	$K_2 - K_1$ (both base e).
Y	$K_1 K_2$ (Both base e).
Z	24(BKLOD)(VEL).
ZSL	24(SLOAD)(VEL).

DIGITAL COMPUTER PROGRAM IBM FORTRAN II

OXYGEN SAG PROGRAM

```
C     THIS PROGRAM IS DESIGNED TO DETERMINE THE FLOW IN CFS
C     REQUIRED IN A STREAM AT A GIVEN POINT TO MAINTAIN A MINI-
C     MUM STATED DISSOLVED OXYGEN CONCENTRATION IN PARTS PER
C     MILLION.  IF REQUIRED FLOW AT ANY POINT IS GREATER THAN
C     THAT PRESENT, THE PROGRAM WILL SEARCH THE RIVER SYSTEM
C     FOR STORAGE RESERVOIRS FROM WHICH WATER COULD BE RELEASED
C     TO AUGMENT THE FLOW AND DETERMINE THE SIZE OF RELEASE
C     NECESSARY TO MEET DOWNSTREAM REQUIREMENTS.  DISSOLVED
C     OXYGEN CONCENTRATION IS THE ONLY QUALITY PARAMETER BEING
C     CONSIDERED.  ALL DECISIONS ARE BASED ON THIS PARAMETER.
0001 FORMAT(F4.0,F2.0,F5.1,F6.1,2F8.0,F6.1,F6.2,F6.1,3F4.1,F7.0/
    22F5.1,F4.1,F6.3,2F8.5,F8.6,F6.3,2F5.1,2F6.0)
     DIMENSION TAB(61,30)
0099 READ 103, K
0103 FORMAT (13)
     DO 110 I = 1,K
0110 READ1,TAB(I,1),TAB(I,2),TAB(I,3),TAB(I,4),TAB(I,5),TAB(I,6),
    2TAB(I,7),TAB(I,8),TAB(I,9),TAB(I,10),TAB(I,11),TAB(I,12),
    3TAB(I,13),TAB(I,14),TAB(I,15),TAB(I,16),TAB(I,17),TAB(I,18),
    4TAB(I,19),TAB(I,20),TAB(I,21),TAB(I,22),TAB(I,23),TAB(I,24),
    5TAB(I,25)
    I = 1
    KOUNT = 0
```

```
     HUNTER = 0.0

     LFLAG = 0

     N1 = 0

     LINE = 26

     N2 = 0

     N4 = 0

     N3 = 0

     QMUP = 0.0

     BODBU = 0.0

     BODTU = 0.0

     BODMU = 0.0

     DOBUP = 0.0

     DOTUP = 0.0

     DOMUP = 0.0

     KNT = 0

     QOVER = 0.0

0002 QDIL = TAB(I,5)

     TAB(I,30) = QDIL

     BODSP = 5.39 * TAB(I,24) * TAB(I,8)

     TAB(I,26) = BODSP

     DOSP = 5.39 *TAB(I,10) * TAB(I,8)

     TAB(I,27) = DOSP

     BODIP = 5.39 * TAB(I,22) * TAB(I,7)

     TAB(I,28) = BODIP

     DIP = 5.39 * TAB(I,11) * TAB(I,7)
     TAB(I,29) = DIP
     I = I + 1
     IF(1.0 - TAB(I,1))2,2,70
0070 I = 1
0004 IF(2.0 - TAB(I,2))27,6,6
0006 IF(1.0 - TAB(I,2))7,23,72
0007 IF(1.0 - TAB(I,5))111,121,121
0111 KNT = KNT + 1
     IF (2 - KNT)77,115,116
0115 QTUPT = QTUP
     BODTUT = BODTU
     DOTUPT = DOTUP
0116 QTUP = 0.0
     QBUP = 0.0
     BODTU = 0.0
     DOTUP = 0.0
0121 QUP = QTUP + QBUP
     QSUM = QUP + TAB(I,7) + TAB(I,8) + TAB(I,30)
     IF(1.0 - QUP)8,8,9
0009 IF(1.02 * TAB(I,6) - QSUM)77,201,201
0201 IF(0.98 *TAB(I,6)  - QSUM)8,8,10
0010 N1 = N1 + 1
     IF(2-KNT)77,311,310
0311 N4 = N4+1
     GO TO 8
```

```
0310 N2 = N2+1
0008 BODDP = 5.39 * TAB(I,23) * TAB(I,30)
     DDP = 5.39 * TAB(I,12) * TAB(I,30)
     SUMBOD = BODTU + BODBU + TAB(I,26) + TAB(I,28) + BODDP
     DOSAP = 5.39 * TAB(I,15) * (QUP + TAB(I,8))
     DEFSUM = (DOSAP - DOTUP - DOBUP - TAB(I,27)) + TAB(I,29) + DDP
     DOBUP = 0.0
     BODBU = 0.0
     QBUP = 0.0
     GO TO 101
0023 QSUM = QBUP + TAB(I,8) + TAB(I,7) + TAB(I,30)
     IF (1.0 - QBUP)26,26,24
0024 IF(1.02 * TAB(I,6) - QSUM)77,202,202
0202 IF(0.98 *TAB(I,6)  - QSUM)26,26,25
0025 N1 = N1 + 1
     IF(2-KNT)77,124,125
0124 N4 = N4 + 1
     GO TO 26
0125 N2 = N2 + 1
0026 BODDP = 5.39 * TAB(I,23) * TAB(I,30)
     DDP = 5.39 * TAB(I,12) * TAB(I,30)
     SUMBOD = BODBU + TAB(I,26) + TAB(I,28) + BODDP
     DOSAP = 5.39 *TAB(I,15) * (QBUP + TAB(I,8))
     DEFSUM = (DOSAP - DOBUP - TAB(I,27)) + TAB(I,29) + DDP
     GO TO 101
0027 N2 = 0
```

```
     N4 = 0
0117 QSUM = QMUP + QTUP + QTUPT + TAB(I,7) + TAB(I,8)
0119 SUMBOD = BODMU + BODTU + TAB(I,26) + TAB(I,28) + BODTUT
     KNT = 0
     QTUPT = 0.0
     DOSAP = 5.39 * TAB(I,15) * (QSUM - TAB(I,7))
     DEFSUM = (DOSAP-DOTUP-DOTUPT-DOMUP-TAB(I,27)) + TAB(I,29)
     QMUP = 0.0
     BODMU = 0.0
     DOMUP = 0.0
     BODTUT = 0.0
     DOTUPT = 0.0
     BODTU = 0.0
     QTUP = 0.0
     DOTUP = 0.0
0101 IF(1.0 - TAB(I,9))17,18,18
0017 QSUMP = QSUM - TAB(I,9)
     RATIO = QSUMP / QSUM
     SUMBOD = RATIO * SUMBOD
     DEFSUM = RATIO * DEFSUM
     QSUM = QSUMP
0018 REK2 = (TAB(I,18) * QSUM ** TAB(I,19)) * 2.31
     IF (REK2 - TAB(I,17))181,180,181
0180 REK2 = REK2 + 0.010
0180 VEL = (TAB(I,20) * QSUM ** TAB(I,21))/1.47
```

```
     X = REK2 - TAB(I,17)
     Y = TAB(I,17) * REK2
     Z = 24.0 * TAB(I,25) * VEL
     ZSL = 24.0 * TAB(I,13) * VEL
     W = (Y*SUMBOD) + (X * (ZSL - REK2 * DEFSUM))-(Z*TAB(I,17))
     U = (TAB(I,17) ** 2.0 * SUMBOD) -(TAB(I,17)*Z)
     R = W / U
     IF(R-0.00)20,20,80
0080 TIMEC = (1.0 / X) * LOGF(R)
     IF (TIMEC - 0.02)20,20,19
0020 TIMEC = 0.0
0019 CRMILE = 24.0 * VEL * TIMEC
     TEND = TAB(I,3) / (24.0 * VEL)
     E = 2.71828
     A = E**(-TAB(I,17)*TEND)
     B = E ** (-REK2 * TEND)
     C1 = TAB(I,17) * SUMBOD
     C = (C1 / X) * (A - B)
     F = REK2 * (1.0 -A)
     G = TAB(I,17) * (1.0 - B)
     AA = Z / REK2
     BB = ZSL / REK2
     DEND = C + (AA *((F-G)/X)) + (BB *(1.0 - B)) + (B * DEFSUM)
     IF (DEND - 0.0)810,811,811
0810 DEND = 0.0
0811 IF (TAB(I,3) -CRMILE)21,21,81
```

```
0081 IF (0.02 - TIMEC)22,22,82
0082 DCLBS = DEFSUM
     GO TO 12
0021 DCLBS = DEND
     TIMEC = TEND
     CRMILE = TAB(I,3)
     GO TO 12
0022 CC = E ** (-TAB(I,17)*TIMEC)
     CC1 = TAB(I,17) * CC * SUMBOD
     DCLBS = (CC1 + (Z * (1.0 - CC)) + ZSL) / REK2
0012 DCPPM = DCLBS / (5.39 * QSUM)
     DOCPPM = TAB(I,15) - DCPPM
     IF (1 - N1)213,213,32
0213 IF(1.02 * TAB(I,6) - QSUM)77,203,203
0203 IF(0.98 * TAB(I,6) - QSUM)32,32,28
0028 QREQD = QSUM * (TAB(I,15)-DOCPPM)/(TAB(I,15)-TAB(I,16))
     IF (QSUM - QREQD)35,29,29
0029 IF(LFLAG - 1)32,30,77
0030 IF((0.01 * TAB(I,6)) - ABSF(QREQD - QSUM))31,33,33
0031 IF(HUNTER - TAB(I,1))34,90,77
0090 N = NHOLD
     HUNTER = 0.0
     GO TO 50
0032 QREQD = QSUM
     IF(DOCPPM - 0.0)77,77,34
```

```
0033 LFLAG = 0
     NHOLD = 0
0034 Q539 = 5.39 * QSUM
     DENDPM = DEND / Q539
     BODNDP = SUMBOD * A
     BODEND = BODNDP / Q539
     DOSAP = Q539 *TAB(I,15)
     DOENDP = DOSAP - DEND
     DOEND = DOENDP / Q539
     IF(2.0 - TAB(I,2))37,38,38
0037 QMUP = QSUM
     BODMU = BODNDP
     DOMUP = DOENDP
     GO TO 41
0038 IF(1.0 - TAB(I,2))39,40,40
0039 QTUP = QSUM
     BODTU = BODNDP
     DOTUP = DOENDP
     GO TO 41
0040 QBUP = QSUM
     BODBU = BODNDP
     DOBUP = DOENDP
0074 FORMAT(1H, 2F6.0,F10.0,4F9.2,F9.1,2F10.3,3F8.1,F12.5,F8.1)
0073 FORMAT(1H2,1X,4HRENO,3X,5HDIGIT,4X,4HQSUM,4X,6HDOCPPM,4X,5HDCP
    24X,5HDOEND,3X,6HDENDPM,3X,6HBODEND,5X,5HTIMEC,5X,4HTEND,3X,
    36HCRMILE,3X,5HRELEN,3X,5HRIVMI,7X,4HREK2,5X,4HTEMP)
0750 FORMAT(1H2,1X,4HRENO,3X,5HDIGIT,4X,4HQDUP,6X,3HVEL,4X,6HDOCPPM)
0041 QDUP = QSUM
     IF(1 - KOUNT)77,75,141
0760 PRINT 750
     LINE = 0
0141 IF(26 - LINE)760,760,98
0098 PRINT 74, TAB(I,1),TAB(I,2),QDUP,VEL,DOCPPM
     LINE = LINE + 1
0072 IF(1.0 - TAB(I,1))79,79,71
0071 KOUNT = KOUNT + 1
     QMUP = 0.
     BODMU = 0.0
     DOMUP = 0.0
     I = 1
     N1 = 0
     LINE = 26
     GO TO 4
0075 IF(1.0 - TAB(I,1))762,762,77
0762 IF(26 - LINE)763,763,76
0763 PRINT 73
     LINE = 0
0076 PRINT 74,TAB(I,1),TAB(I,2),QSUM,DOCPPM,DCPPM,DOEND,DENDPM,BODEND,
    2TIMEC,TEND,CRMILE,TAB(I,3),TAB(I,4),REK2,TAB(I,14)
     LINE = LINE + 1
0079 I = I + 1
```

```
     GO TO 4
0077 PAUSE
0102 FORMAT(1H,1X,4HRENO,2X,4HHUNT,2X,5HDIGIT,2X,5HTIMEC,2X,6HDOCPPM,
    23X,3HKNT,3X,5HKOUNT,2X,2HN1,4X,2HN2,4X,2HN3,4X,2HN4,3X,5HLFLAG,
    34X,5HQREQD,7X,5HQOVER,8X,4HQSUM)
1102 FORMAT(1H,3F6.0,2F7.3,716,3F12.0)
     PRINT 102
     PRINT 1102,TAB(I,1),HUNTER,TAB(I,2),TIMEC,DOCPPM,KNT,KOUNT,N1,N2,
    2N3,N4,LFLAG,QREQD,QOVER,QSUM
     IF(1.0 - TAB(I,6))99,13,13
0013 STOP
0035 IF(0.10 - ABSF(DOCPPM - TAB(I,16)))36,34,34
0036 HUNTER = TAB(I,1)
     IF(LFLAG - 1)43,45,77
0043 LFLAG = 1
     GO TO 44
0045 QOVER = 0.0
0044 IF(2.0 - TAB(I,2))46,47,47
0047 IF(1.0 - TAB(I,2))48,49,49
0049 N = 1
     N1 = N1 -1
     IF(2-KNT)77,126,127
0126 N4 = N4 - 1
     GO TO 50
0127 N2 = N2 - 1
```

```
     GO TO 50
0048 IF(2-KNT)77,147,148
0147 N = N4
     N1 = N1 -N4
     N4 = 0
     GO TO 50
0148 N = N2
     N1 = N1 - N2
     N2 = 0
     GO TO 50
0046 N = N1
     N1 = 0
0050 DELTAQ = QREQD - QSUM
     FNUM = N
     QEACH = DELTAQ / FNUM
0052 IF(1.0 - TAB(I,5))53,53,51
0051 I = I - 1
     GO TO 52
0053 IF(TAB(I,6)-(TAB(I,30)+TAB(I,7)+TAB(I,8)))54,54,55
0055 QDIL = TAB(I,30) + QEACH
     N3 = N3 +1
     QSUM = QDIL + TAB(I,7) + TAB(I,8)
     IF(1.01 *TAB(I,6) - QSUM)57,61,61
0057 QOVER = QSUM
     QDIL = TAB(I,6) - QSUM + QDIL
     QSUM = TAB(I,6)
0061 TAB(I,30) = QDIL
     IF(N - N3)77,59,51
0059 NHOLD = N
     N3 = 0
     GO TO 4
0054 IF(1.0 - QOVER)69,51,51
0069 IF(1.02 * TAB(I,6) - QSUM)77,205,205
0205 IF(0.98 * TAB(I,6) - QSUM)51,51,60
0060 N3 = N3 + 1
     QOVER = QOVER + QEACH
     IF(QOVER - TAB(I,6))62,62,61
0062 QDIL = QOVER - QSUM + QDIL
     QSUM = QOVER
     QOVER = 0.0
     GO TO 61
     END
```

Explanation of Input Data Sheets

There are two input data cards for each reach and these are listed in consecutive rows on the input data sheets such as shown on Page 80. The number 011 seen immediately at the top of the page is "K" or the number of reaches included in this river system. The top two rows are the data for the first reach, the third and fourth rows are the data for the second reach and etc. The format or column headings proceeding from left to right along the first row are: RENO, DIGIT, RELEN, RIVMI, QMIN, QMAX, QI, QS, QOUT, DOS, DI, DD, SLOAD; and across the second row: TEMP, DOSAT, DOMIN, DOXK1, AK2, BK2, CVEL, DVEL, BODI, BODD, BODS, and BKLOD.

INPUT DATA FOR MODEL RIVER SYSTEM

```
011
 105  2   70  180   960   1760   400   100   00   00   00   00     0
  134  105   80  0253  181100  000000 2350000  0000    00   00  1    0
 103  1   72   72    30     40   100   010   00   00   00   00     0
  134  105   80  0253  375600  000000 2350000  0000    00   00  1    0
 101  2  110  110      0   1680   600   100 1800   00   00   00     0
  134  105   80  0253  181100  000000 2350000  0000    00   00  1    0
  96  2   80  280   550    550    00   100   00   00   00   00     0
  180   95   80  0750  253600  000000 0057700  0461    00   00  1    0
  95  2  200  200   000    650   850  1500   00   00   80   00     0
  180   95   80  0750  214300  000000 0057700  0461    00   00 3000  00
  89  3  110 1870     0   2360   300   100   00   00   00   00     0
  160  100   70  0500  077320 -005333 0018600  0576    00   00  1    0
  88  3  110 1760     0   2390   300   100   00   00   00   00     0
  160  100   72   500   77320 -005333   18600   576    00   00  1    0
  87  3  110 1650     0   2420   300   100   00   00   00   00     0
  160  100   78   500   77320 -005333   18600   576    00   00  1    0
  86  3  110 1540     0   2450   300   100   00   00   00   00     0
  160  100   50  0500  077320 -005333 0018600  0576    00   00  1    0
  85  3  110 1430     0   2480   300   100   00   00   00   00     0
  160  100   80  0500  077320 -005333 0018600  0576    00   00  1    0
000000000

  0 0   00    00       0      10    00   000    00   0
```

INPUT DATA FOR WILLAMETTE RIVER SYSTEM

```
046
105   2    70  180  1720  1760    400    031      00    00   10   10    0
 134  105   60  253  181100  00000 2350000   000    10   06   16    0
103   1    72   72    30    40    100    000      00    00   10   09    0
 134  105   60  253  375600  00000 4000000   000    01   00    0    0
101   2   110  110     0  1680    600    000  1800    00   10   00    0
 134  105   60  253  181100  00000 2350000   000    10   00    0    0
 99   2    70   70   630   650    200    000      00    00   10   09    0
 180   95   60  312  486000  00000  100000   501    10   05    0    0
 97   1    80  280   125   135    100    000      00    00   10   09    0
 180   95   60  312  438000  00000  615000   208    10   05    0    0
 96   2   120  200     0   800    150    101      00    00   10   00    0
 180   95   60  312  253600  00000  057700   461    10   00   80    0
 95   2    80   80     0   810    100    000      00    00   10   00    0
 180   95   60  312  214300  00000  057700   461    10   00    0    0
 93   3    20 1870     0  2490     00    009      00    00   10   00    0
 150  102   60  270   77320 -005333  018600   576    10   00  161    0
 91   3    50 1850     0  2520    240    605      00    00   10   00    0
 160  100   60  282   77320 -005333  018600   576    10   00   28    0
 89   3    40 1800     0  2540     50   1490      00    00   10   00    0
 166   99   60  292   56690 -005333  006150   712    10   00  165    0
 85   2    30  560  1435  1445    100    000      00    00   00   00    0
 160  100   60  296  480400  00000 6000000   000    01   00    0    0
 81   2   150  530     0  1680   2350    000      00    00   00   00    0
```

```
160  100    60 296    150000   00000 2250000    000    01    00     0      0
79  2    280  380       0  1790   1100    000    00    00    00    00      0
160  100    60 296    134930   00000 2200000    000    10    00     0      0
77  2    100  100       0  1840    400   1031    00    00    10    00      0
170   97    60 310     95337   00000 2000000    000    10          59      0
75  3    120  1760      0  4380     00    002    00    00    10    00      0
180   95    60 312     95147 -006383 022900     585    10    00   400      0
73  3    210 1640       0  4500   1200    056    00    00    10    00      0
185   94    60 320     95147 -006383 022900     585    10    00   185      0
71  2    126  236     30     35     50    000    00    00    10    05      0
215   89    60 345    193500    0000 750000     000    10    14     0      0
70  2    110  110       0     35     00    008    00    00    10    00      0
215   89    60 345    193500   00000 500000     000    10    00   180      0
69  3     80 1430       0  4610    750    000    00    00    10    00      0
195   93    60 335     40600   00000 006020     698    10    00     0      0
67  2     75   75     20     20     00    018    00    00    10    07      0
210   90    60 340    229800    0000 750000     000    10    16    65      0
65  3    150 1350       0  4700    450   2636    00    50    10    00      0
195   93    60 335    134600 -009309 032520     513    10    00   106      0
64  2    100  500     30     30     00    000    00    00    10    05      0
200   92    60 330    520000   00000 3000000    000    10    03     0      0
63  2    100  400       0     30     00    000    00    00    10    00      0
200   92    60 330    401330   00000 1500000    000    10    00     0      0
62  2    300  300       0     30     00    011    00    00    10    00      0
200   92    60 330    296550   00000 1000000    000    10    00   175      0
```

```
61   3   110 1200      0  4800    600    830    00    00    10    00       0
200    92    60   342    437650 -024468 025900    527      10    00   145   0
59   2   208   458  1175  1230    550    000    00    00    10    05       0
120   108    60   240    221030  00000 6000000    000      10    05     0   0
57   2   250   250      0  1330   1000    002    00    00    10    00       0
160   100    60   296    191880  00000 5000000    000      10    00   300   0
55   1   125   275   160   180    200    039    00    00    10    05       0
190    94    60   315    232230  00000 2800000    000      10    10    72   0
54   1    30   150      0    60      0      0  1200     0     0     0       0
190    94    60   315    220000  00000 720000     000      10    10     0   0
53   1   120   120      0    75      0   1434     0     0     0     0       0
200    92    60   323    220000  00000 720000     000      10    10   140   0
51   2   110   110      0   725     00    000    00     0     0    00       0
165    98    60   303    145300  00000 2250000    000      10    00     0   0
47   3   250  1090      0  5600    750    000    00    00    10    00       0
195    93    60   335    277544 -017553 088570    391      10    00     0   0
43   3   290   840      0  5900   2700   2948    00    00    10    00       0
200    92    60   342    147679 -010372 038830    489      10    00   240   0
39   2   110   110     30    40     74    262    00    00    10    00       0
220    88    60   350    37900   00000  500000    000      10    24    19   0
37   3    50   550      0  5960    200    000    00    00    10    00       0
210    90    60   358    02435   25000  002410    779      10    00     0   0
35   3   140   500      0  6110   1450    527    00    00    10    00       0
215    89    60   345    00253   31900  000275    859      10    00  1139   0
33   2   150   260     10    20     95    062    00    00    10    15       0
```

```
 200    92    60  300    15000    00000  2400000  000       06    06  860  0
 32  2    110  110      0     30     100    019    00    00    10    00      0
 200    92    60  300    15000    00000  2400000  000       06    00  158  0
 31  3     70  360      0  6220     800    026    00    00    10    00      0
 215    89    60  345    00571    27100  001666    681      10    00  145  0
 29  2    130  590     10     10      00    007    00    00    10    10      0
 220    88    60  350    12000    00000  300000    000      10    10  133  0
 27  2     70  460      0     15      40    095    00    00    10    00      0
 220    88    60  350    12000    00000  300000    000      10    00   92  0
 26  2    110  390      0     35     170    339    00    00    10    00      0
 220    88    60  350    12000    00000  300000    000      10    00   39  0
 25  2    220  280      0     45      90    046    00    00    10    00      0
 220    88    60  350    12000    00000  300000    000      10    00  150  0
 23  2     60   60      0     25      12    397   250    00    10    00      0
 220    88    60  350    12000    00000  300000    000      10    00   37  0
 21  3     30  290      0  6245       00    012    00    00    10    00      0
 215    89    60  345    00571    27100  01666     681      10    00   95  0
 00    00
000000000
```

MOUTH OF TUALATIN R. TO MOUTH OF MOLALLA R.

R.M. 29 to R.M. 36
R.M. = River Mile

	Mean Velocity, fps			Mean Depth, ft		
Flow, cfs	2600	6600	8600	2600	6600	8600
1. R.M. 29	0.142	0.342	0.436	15.8	16.2	16.4
2. R.M. 30	0.407	0.973	1.236	22.0	22.3	22.6
3. R.M. 31	0.190	0.448	0.574	19.2	19.9	20.1
4. R.M. 33	0.276	0.565	0.690	13.2	14.9	15.4
5. R.M. 34	0.332	0.718	0.890	17.0	16.8	16.8
6. R.M. 35	0.420	0.862	1.05	11.8	12.8	13.2
7. R.M. 36	0.289	0.638	0.792	16.6	17.1	17.5
TOTAL	2.056	4.546	5.668	115.6	120.0	122.0
Average:	0.366	0.652	0.809	16.51	17.14	17.43

Using O'Connor's equation:

$$k_2 = \frac{(D_L\ U)^{\frac{1}{2}}}{2.31\ H^{3/2}} \quad @\ 20°\ C$$

D_L = Coefficient of diffusion

U = Mean forward flow velocity

H = Mean depth

$D_L = 6.7 \times 10^{-2}$ cm^2/hr.

from F & G, p. 446
Rich, Unit Operation in
San. Engr., p. 174.

$= 7.00 \times 10^{-s}$ ft^2/hr.

1.70×10^{-3} ft^2/day

$(1.70 \times 10^{-3}$ ft^2/day$)(86{,}400$ sec/day$)^{*} = \underline{\underline{146.88}}\ \frac{\text{sec ft}}{\text{day}^2}$

*Used to allow use of velocity in feet per second.

Q = 2600 cfs

$$k_2 = {\frac{(146.88)(0.366)}{2.31\,(16.51)^{3/2}}}^{\frac{1}{2}} = \frac{7.34}{155.5}$$

$\underline{\underline{k_2 = 0.0472}}$ ANS.

Q = 6600 cfs

$$k_2 = {\frac{(146.88)(0.652)}{2.31(17.14)^{3/2}}}^{\frac{1}{2}} = \frac{9.78}{164.2}$$

$\underline{\underline{k_2 = 0.0595}}$ ANS.

Q = 8600 cfs

$$k_2 = {\frac{(146.88)(0.809)}{2.31(17.43)^{3/2}}}^{\frac{1}{2}} = \frac{10.9}{166.5}$$

$\underline{\underline{k_2 = 0.0654}}$ ANS.

by Churchill equation

Q = 2600 cfs

$$k_2 = \frac{5.026(0.366)^{0.969}}{(16.51)^{1.675}} = \frac{1.89}{110}$$

$k_2 = 0.0171$ ANS.

Q = 6600 cfs

$$k_2 = \frac{5.026(0.652)^{0.969}}{(17.14)^{1.673}} = \frac{3.32}{116}$$

$k_2 = 0.0286$ ANS.

Q = 8600 cfs

$$k_2 = \frac{5.026(0.809)^{0.969}}{(17.43)^{1.673}} = \frac{4.09}{119}$$

$k_2 = 0.0343$ ANS.

MOUTH OF MOLALLA RIVER TO NEWBERG

R. M. 37 to R. M. 50

		Mean Velocity, fps			Mean Depth, feet		
Flow, cfs		2600	6600	8600	2600	6600	8600
	R.M.						
1.	37	0.216	0.485	0.609	18.88	20.70	21.25
2.	38	0.164	0.383	0.486	27.96	29.57	30.11
3.	39	0.238	0.526	0.657	16.97	18.69	19.24
4.	40	0.303	0.664	0.826	15.52	17.26	17.78
5.	41	0.232	0.510	0.637	16.37	18.19	18.76
6.	42	0.193	0.438	0.551	20.96	22.48	22.96
7.	43	0.259	0.575	0.718	17.26	18.64	19.11
8.	44	0.274	0.606	0.754	16.74	17.60	17.90
9.	45	0.258	0.559	0.694	14.53	16.37	16.94
10.	46	0.228	0.514	0.645	19.56	21.34	21.92
11.	47	0.276	0.606	0.755	16.21	17.86	18.34
12.	48	0.320	0.681	0.840	12.89	14.59	15.14
13.	49	0.223	0.498	0.625	18.48	20.34	20.92
14.	50	0.138	0.326	0.415	33.84	33.62	33.55
TOTAL		3.322	7.371	9.212	266.17	287.25	293.92
Average:		0.237	0.526	0.658	19.01	20.52	20.95

MOUTH OF MOLALLA RIVER TO NEWBERG

R. M. 37 to R. M. 50

For flow of 2600 cfs

$$k_2 = \frac{\left[(146.88)(0.237)\right]^{\frac{1}{2}}}{2.31(19.01)^{3/2}} = \frac{(34.81)^{\frac{1}{2}}}{191.73}$$

$$= \frac{5.9}{191.7} = \underline{\underline{0.0307 \text{ ANS.}}}$$

For flow of 6600 cfs

$$k_2 = \frac{\left[(146.88)(0.526)\right]^{\frac{1}{2}}}{2.31(20.52)^{3/2}} = \frac{(77.25)^{\frac{1}{2}}}{215.7}$$

$$k_2 = \frac{8.79}{215.7} = \underline{\underline{0.0407 \text{ ANS.}}}$$

For flow of 8600 cfs

$$k_2 = \frac{\left[(146.88)(0.658)\right]^{\frac{1}{2}}}{2.31(20.99)^{3/2}} = \frac{(96.64)^{\frac{1}{2}}}{221.7}$$

$$k_2 = \frac{9.83}{221.7} = \underline{\underline{0.0443 \text{ ANS.}}}$$

$$k_2 = \frac{5.026\ V^{0.969}}{H^{1.673}}$$

For flow of 2600 cfs

$$k_2 = \frac{(5.026)(0.237)^{0.969}}{(19.01)^{1.673}} = \frac{1.246}{138}$$

$$k_2 = \underline{\underline{0.0090}}\ \text{ANS.}$$

For flow of 6600 cfs

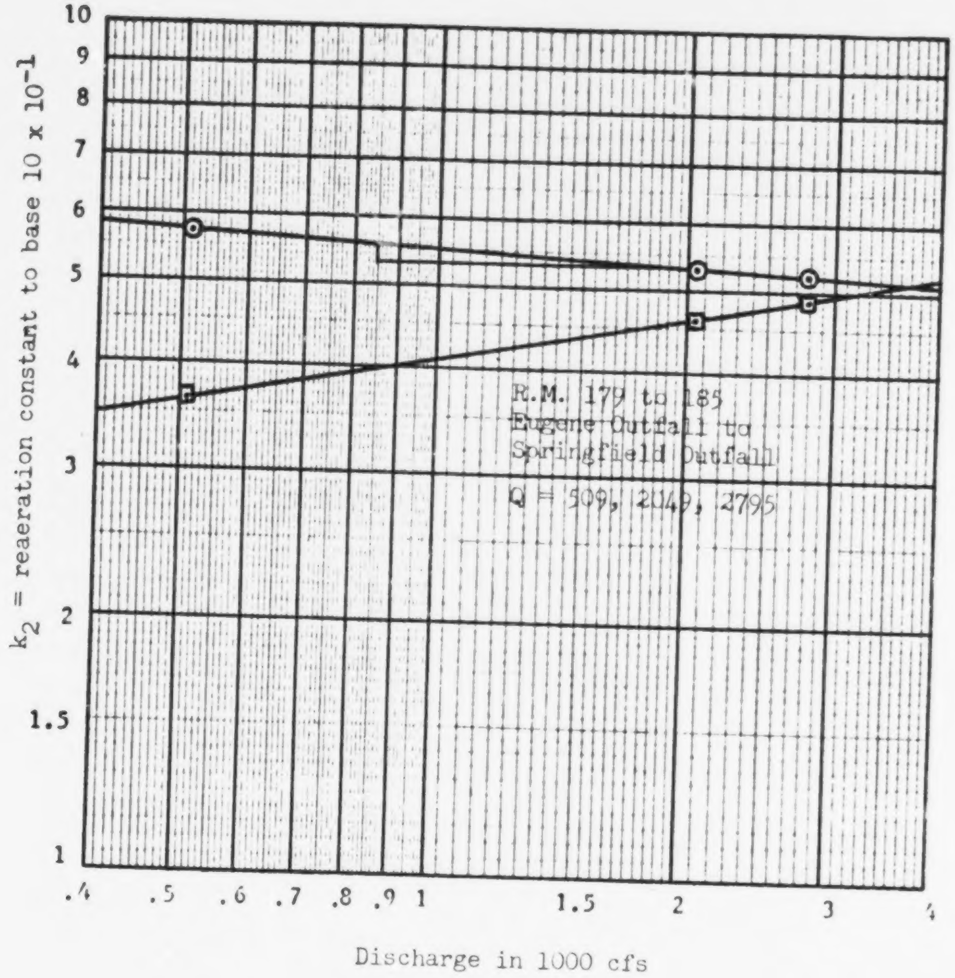
$$k_2 = \frac{(5.026)(0.526)^{0.969}}{(20.52)^{1.673}} = \frac{2.70}{158}$$

$$k_2 = \underline{\underline{0.0170}}\ \text{ANS.}$$

For flow of 8600 cfs

$$k_2 = \frac{(5.026)(0.658)^{0.969}}{(20.99)^{1.673}} = \frac{3.35}{162}$$

$$k_2 = \underline{\underline{0.0206}}\ \text{ANS.}$$



⊙ = O'Connor Equation
⊡ = Churchill Equation

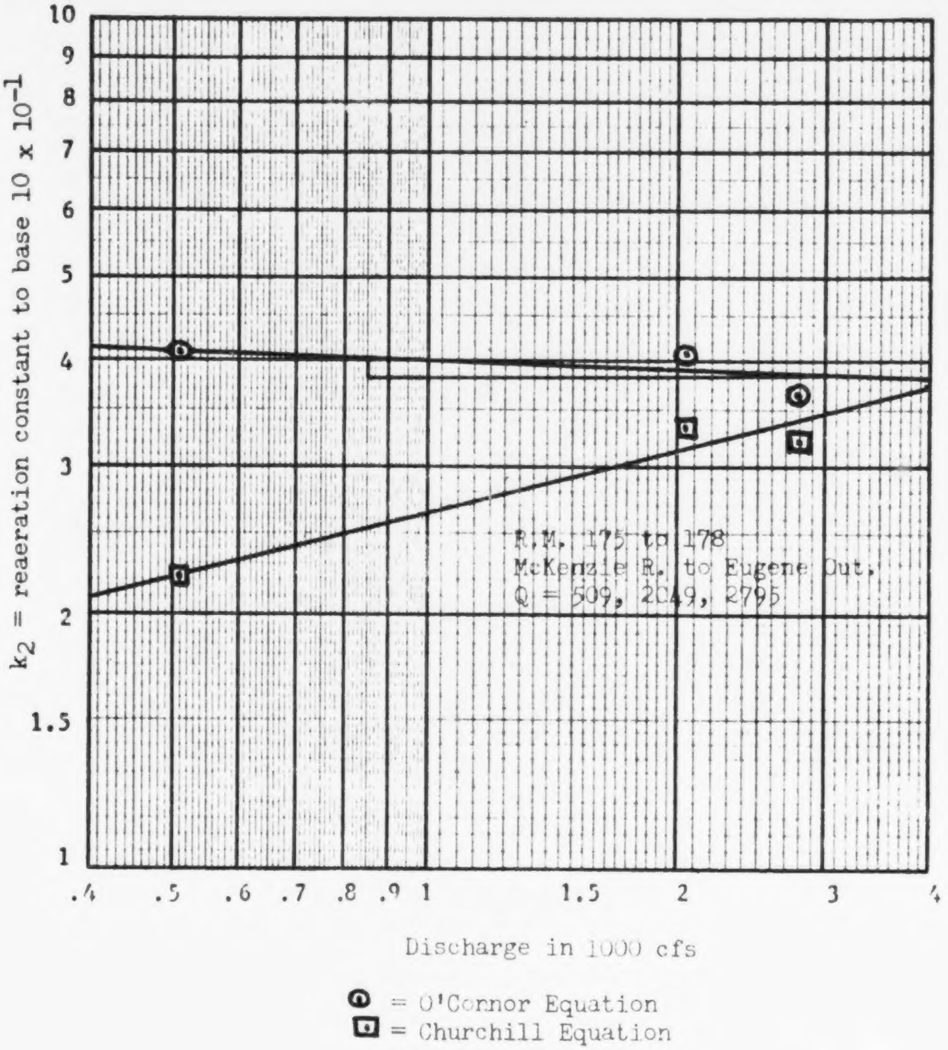
$b = \frac{-20}{375} = -0.05333$

$k_2 = 0.58$ @ $Q = 400$

$k_2 = aQ^{-b}$

$a = 0.58/0.7267 = 0.798$

So $k_2 = 0.798\ Q^{-0.05333}$



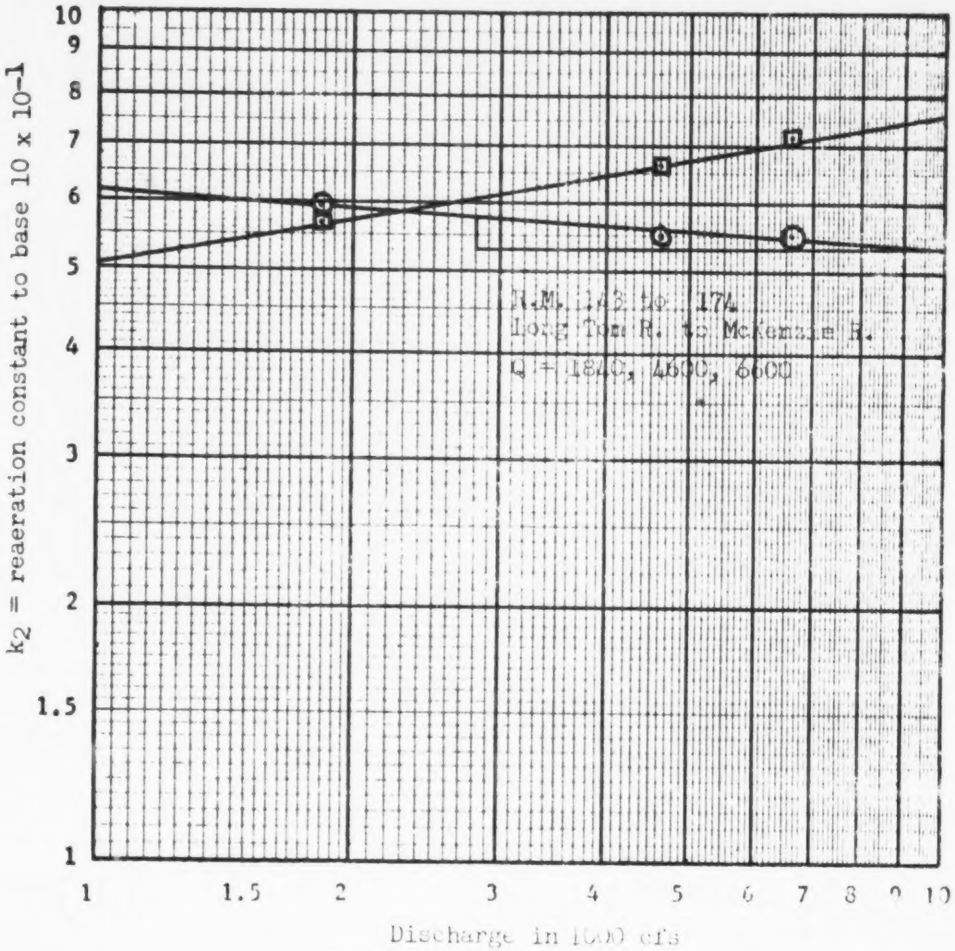
$$b = \frac{-20}{375} = -0.05333$$

$k_2 = 0.39$ @ $Q = 1500$

$k_2 = aQ^{-b}$

$a = 0.39/0.677 = 0.576$

So $k_2 = 0.576\ Q^{-0.05333}$



⊙ = O'Connor Equation
▣ = Churchill Equation

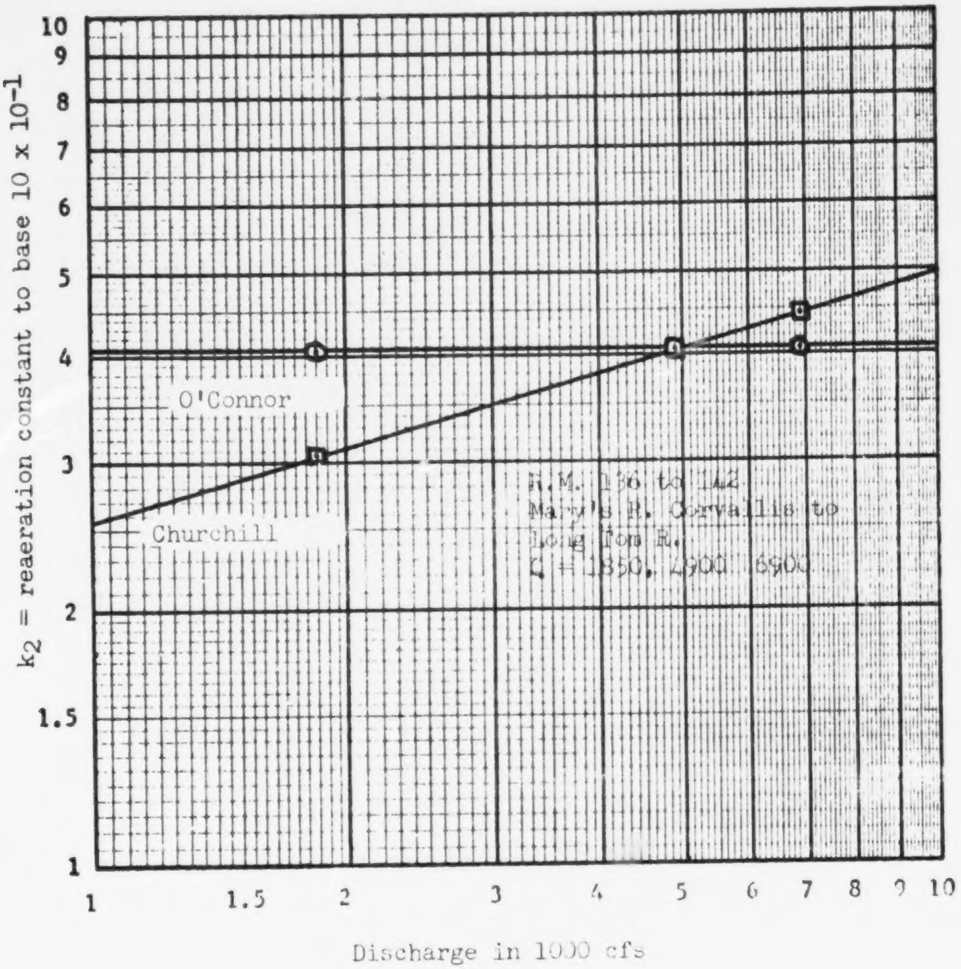
$$b = \frac{-24}{376} = -0.06383$$

$k_2 = 0.58$ @ $Q = 3000$

$k_2 = aQ^{-b}$

$$a = \frac{0.58}{0.5999} = 0.9666$$

So $k_2 = 0.9666\ Q^{-0.06383}$

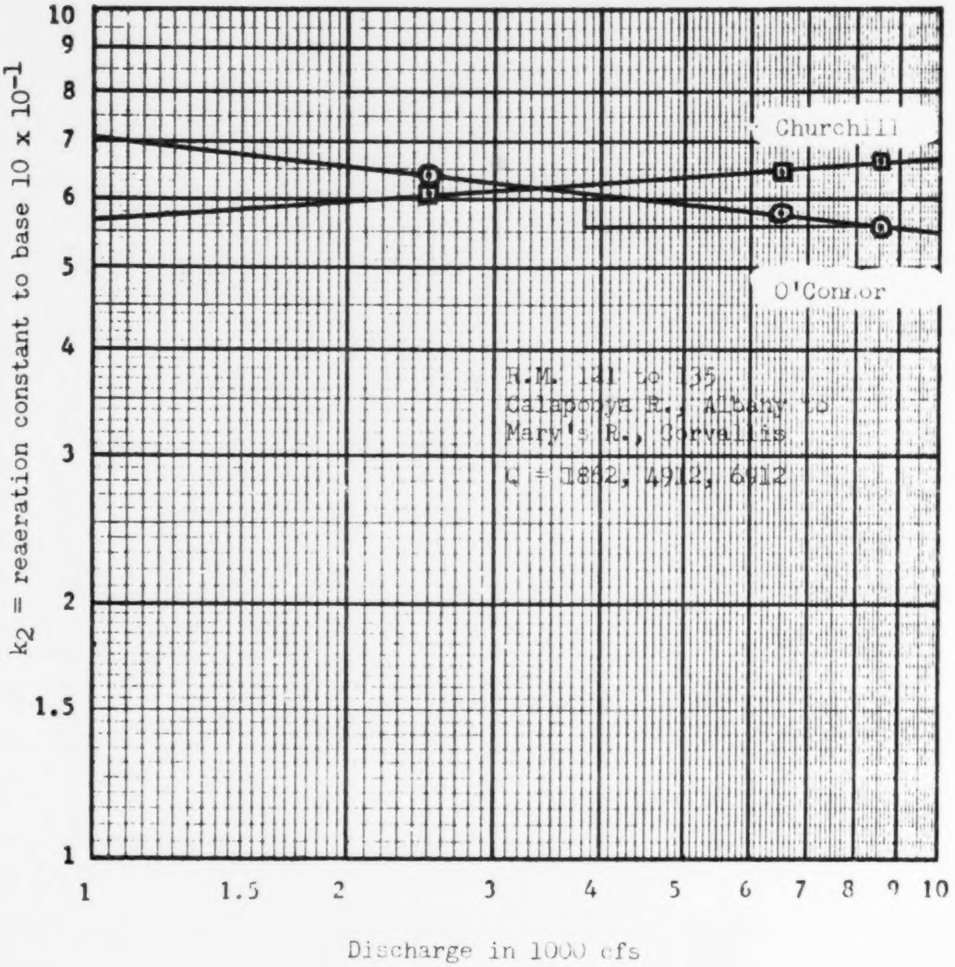


$$b = \frac{0}{376} = 0$$

$$k_2 = aQ^b$$

$$a = 0.406$$

$$\text{So } k_2 = 0.406\ Q^0$$



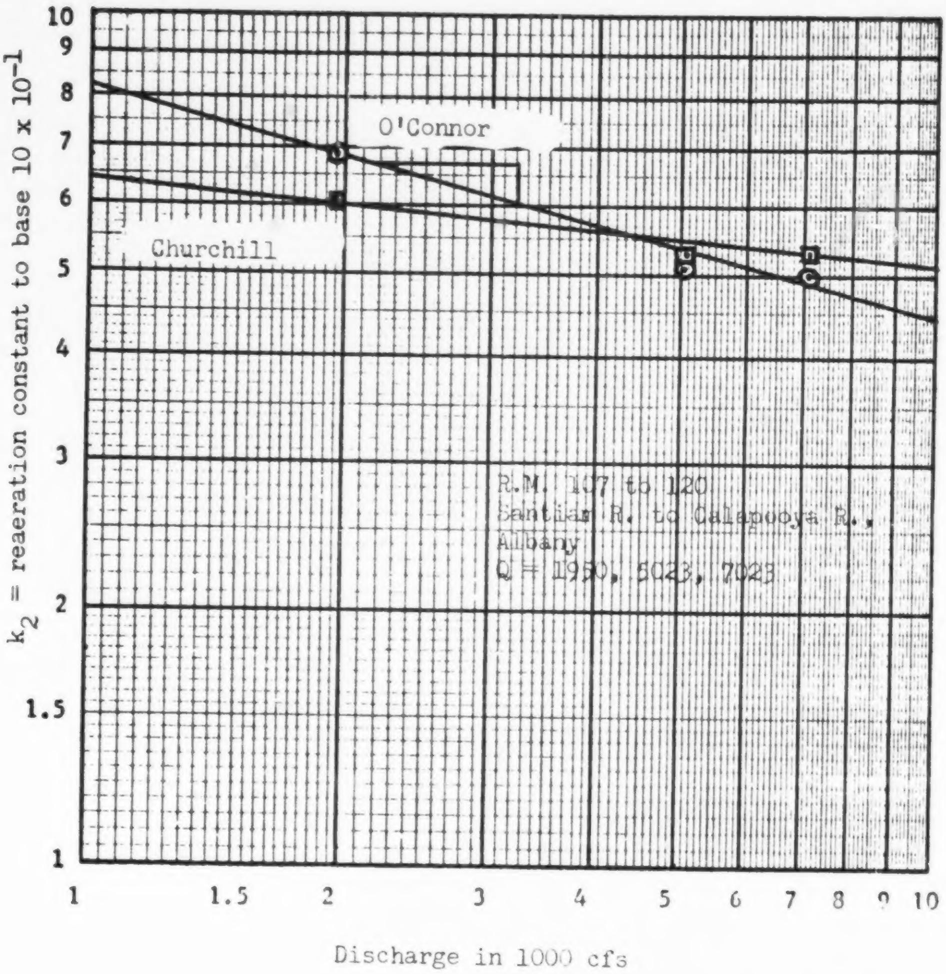
$$b = \frac{-35}{376} = -0.09309$$

$$k_2 = 0.63 \text{ @ } Q = 3500$$

$$k_2 = aQ^{-b}$$

$$a = \frac{0.63}{0.468} = 1.346$$

So $k_2 = 1.346\ Q^{-0.09309}$



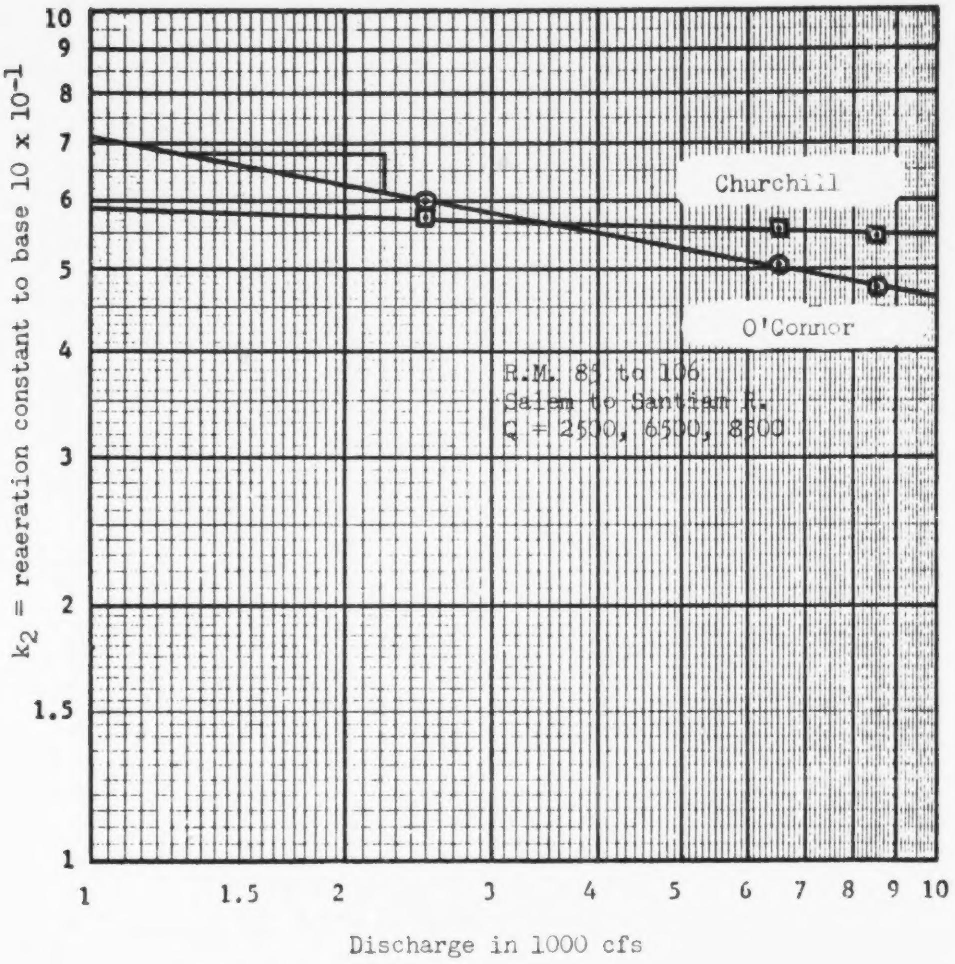
$$b = \frac{-92}{376} = -0.24468$$

$$k_2 = 0.67 \text{ @ } Q = 2000$$

$$0.67 = aQ^{-b}$$

$$a = \frac{0.67}{0.1555} = 4.308$$

So $k_2 = 4.308\ Q^{-0.24468}$



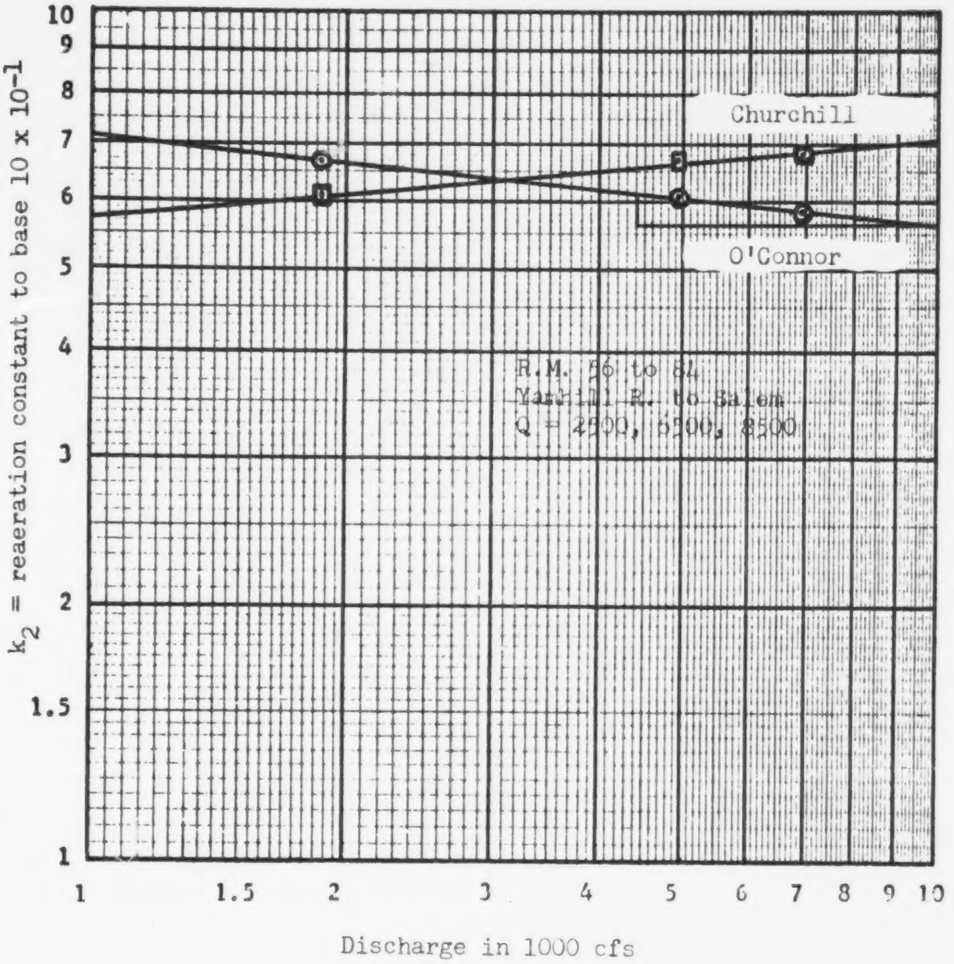
$$b = \frac{-66}{376} = -0.17553$$

$$k_2 = 0.65 \text{ @ } Q = 1600$$

$$0.65 = aQ^{-b}$$

$$a = \frac{0.65}{0.274} = 2.372$$

So $k_2 = 2.372\ Q^{-0.17553}$



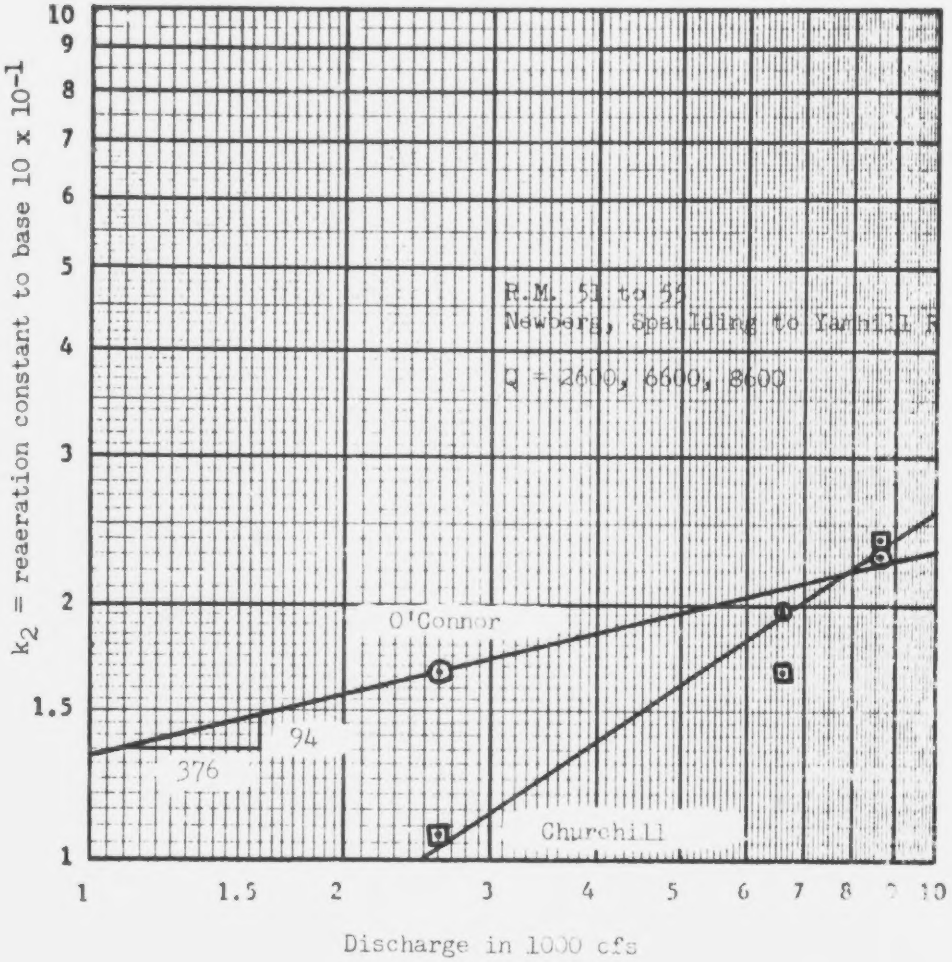
$$b = \frac{-39}{376} = -0.10372$$

$$k_2 = 0.70 \text{ @ } Q = 1000$$

$$0.70 = aQ^{-b}$$

$$a = \frac{0.70}{0.489} = 1.431$$

$$\text{So } k_2 = 1.431\ Q^{-0.10372}$$



R.M. 51 to 55
Newberg, Spaulding to Yamhill R

Q = 2600, 6600, 8600

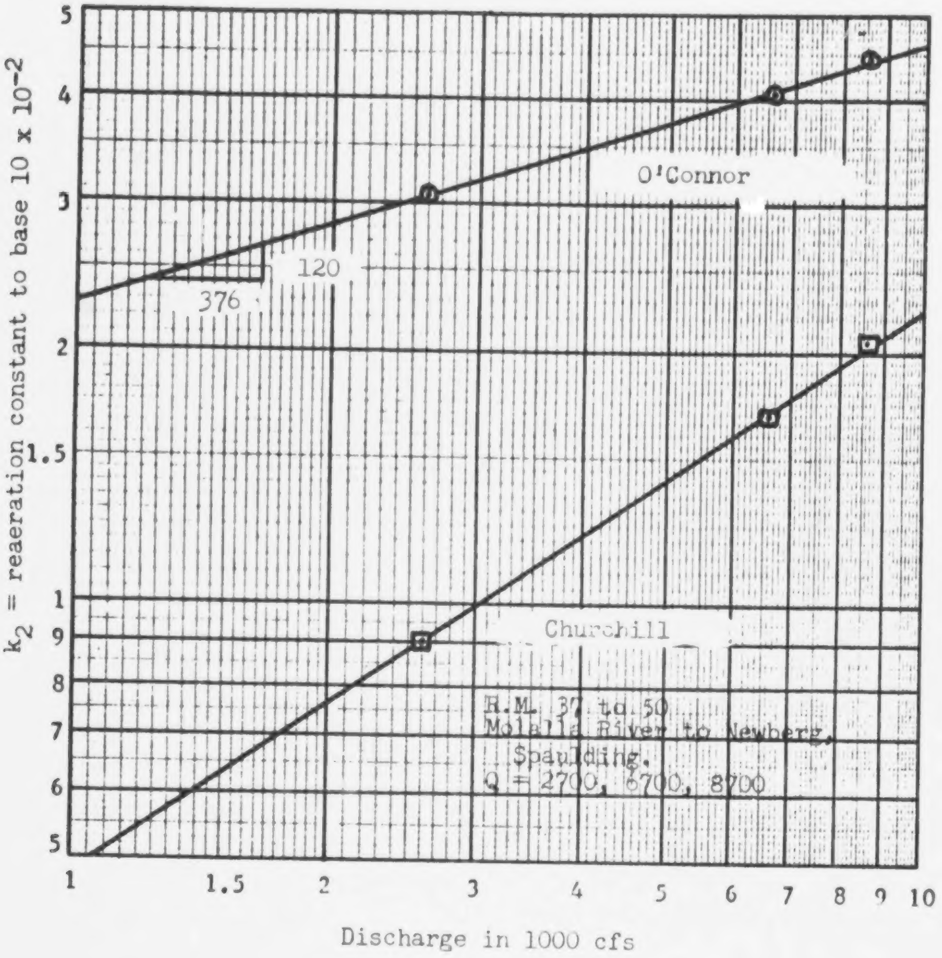
$$b = \frac{94}{376} - 0.250$$

$$k_2 = 0.2 \ @ \ Q - 5200$$

$$0.2 \quad aQ^b$$

$$a = \frac{0.2}{8.48} = 0.0236$$

So $k_2 = 0.0236\ Q^{0.250}$



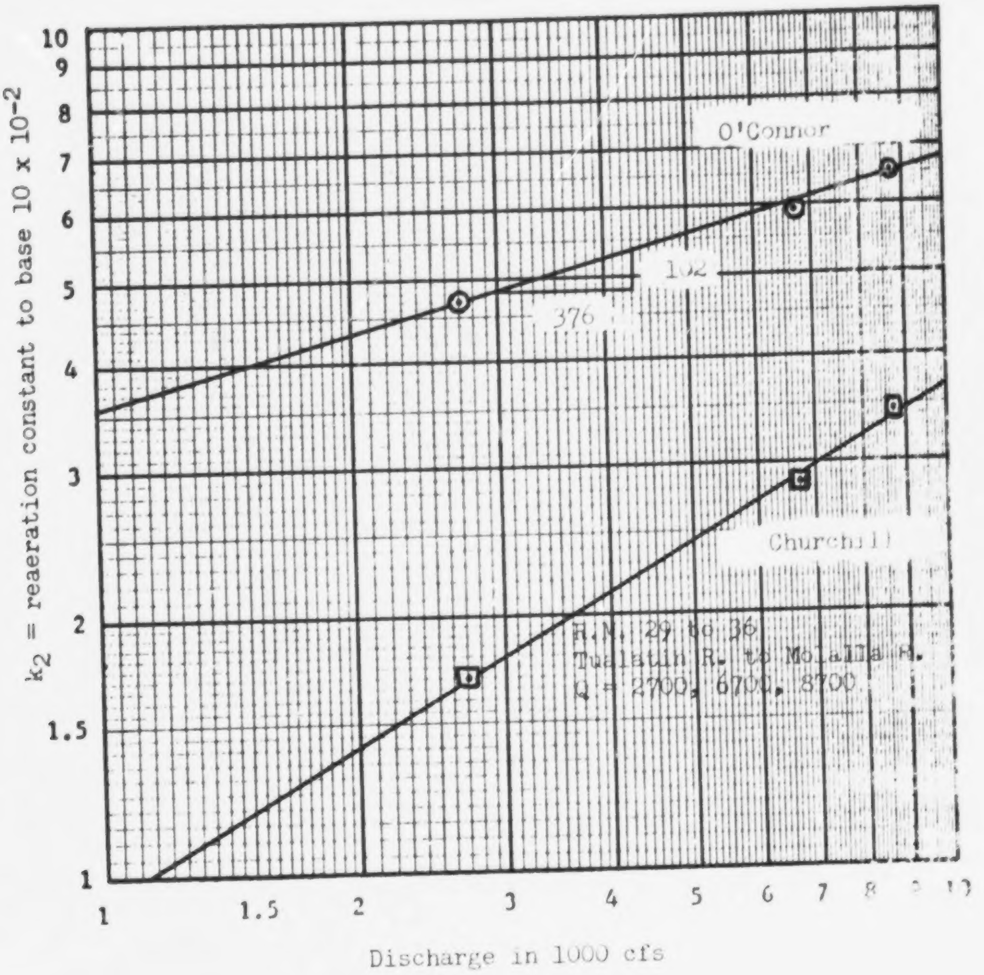
$$b = \frac{120}{376} = 0.319$$

$$k_2 = 0.0275 \text{ @ } Q = 1950$$

$$0.0275 = aQ^b$$

$$a = \frac{0.0275}{11.2} = 0.002455$$

So $k_2 = 0.002455\ Q^{0.319}$



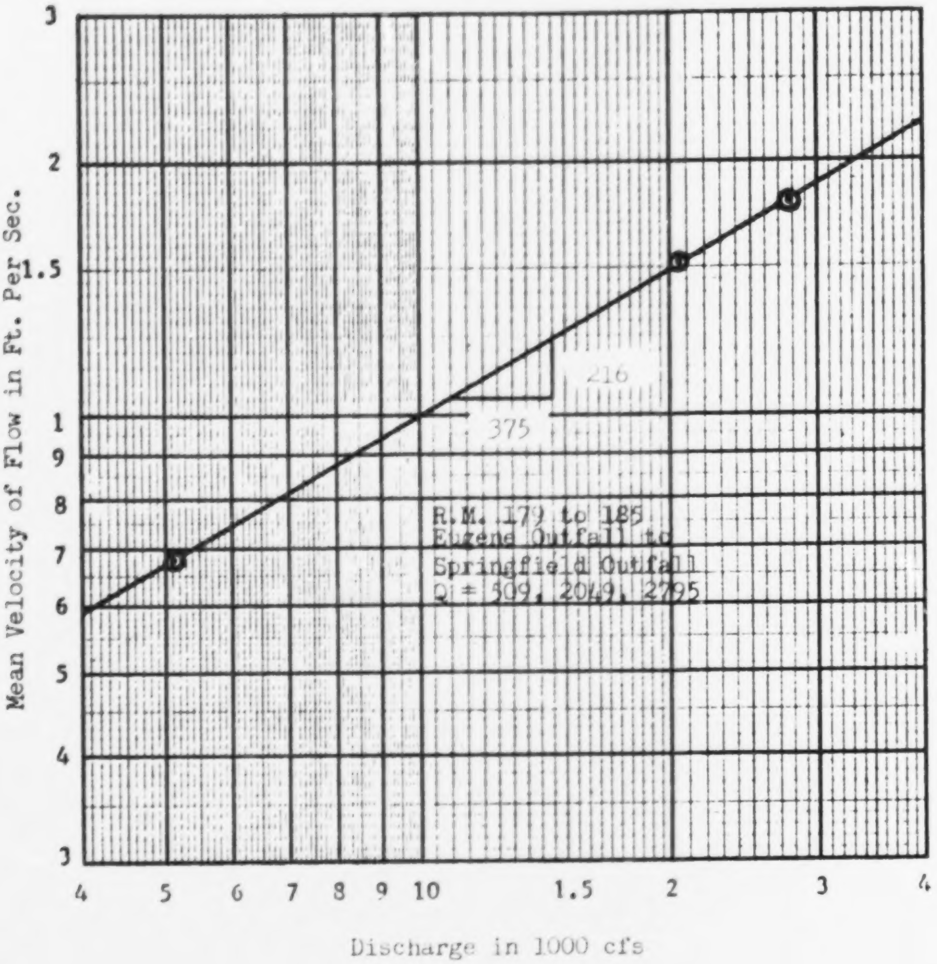
$$b = \frac{102}{376} = 0.271$$

$$k_2 = 0.042 \text{ @ } Q = 1750$$

$$0.042 = aQ^b$$

$$a = \frac{0.042}{7.59} = 0.005534$$

$$\text{So } k_2 = 0.005534\ Q^{0.271}$$



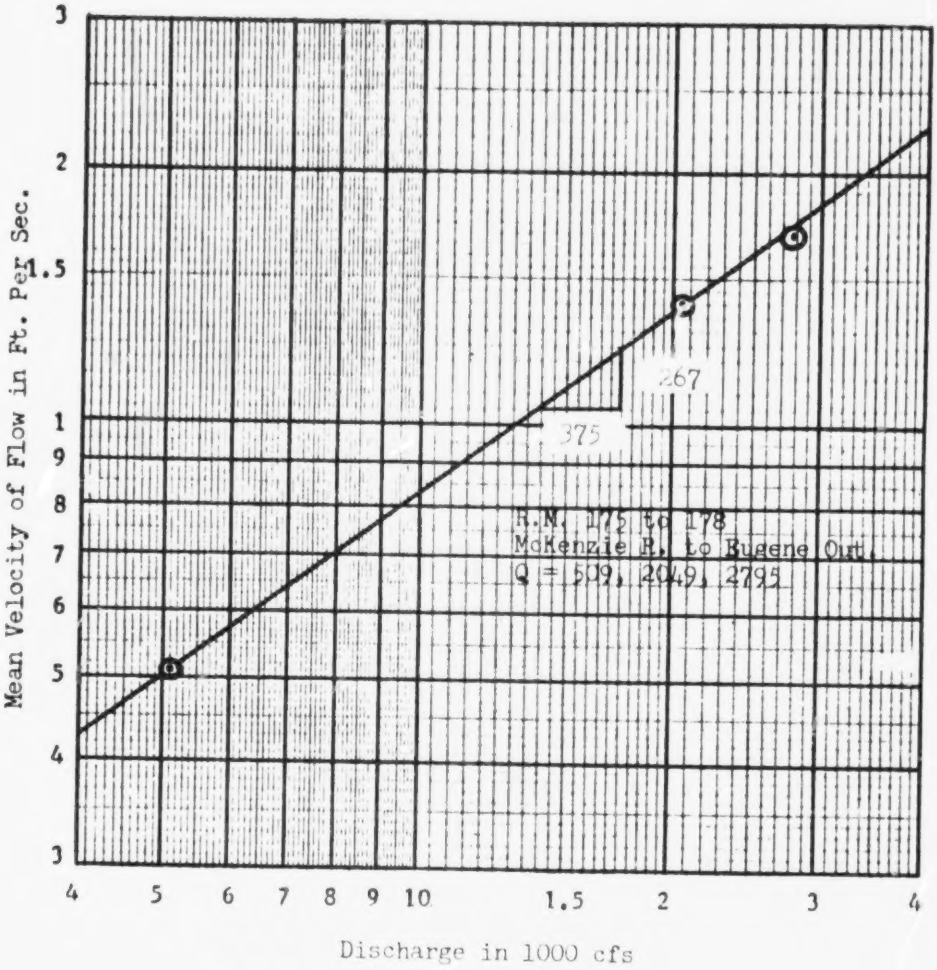
$$d = \frac{216}{375} = 0.576$$

@ $V = 1.0$, $Q = 1000$

$$1.0 = cQ^{d} = c1000^{0.576}$$

$$c = \frac{1}{53.5} = 0.0186$$

So $V = 0.0186\ Q^{0.576}$



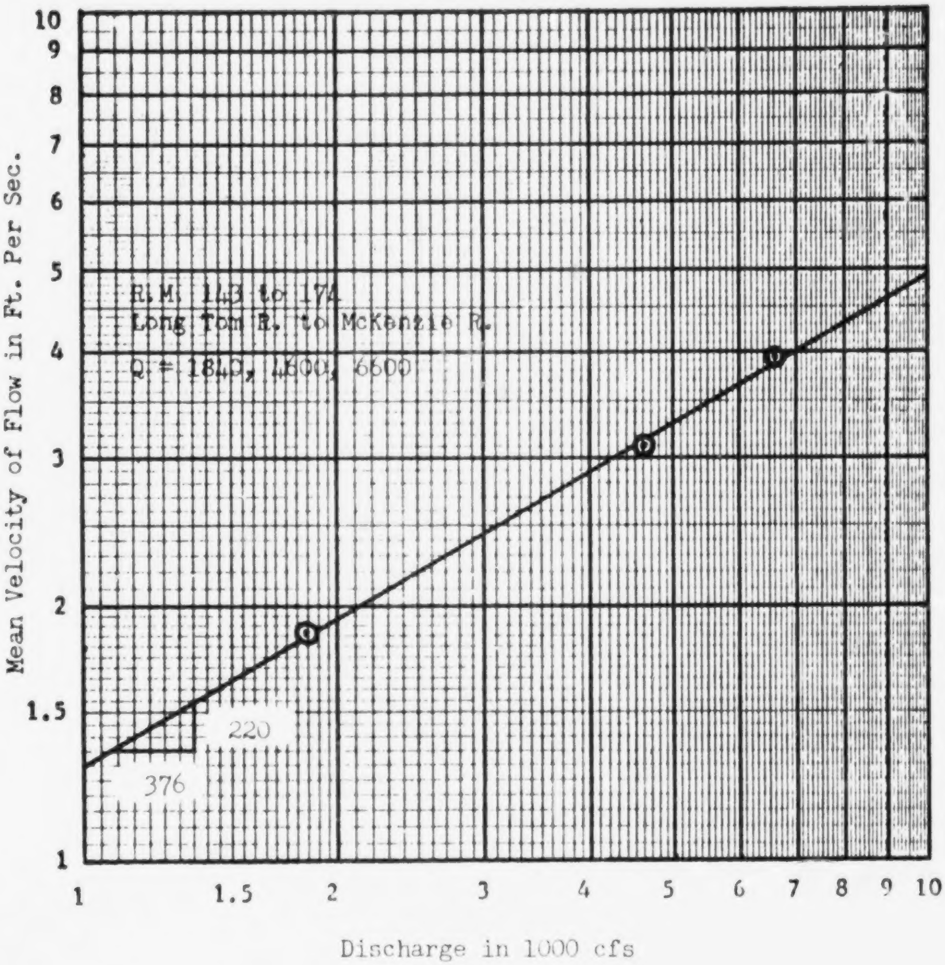
$$d = \frac{267}{375} = 0.712$$

$$@\ Q = 1000,\ V = 0.84$$

$$0.84 = cQ^{d} = c1000^{0.712}$$

$$c = \frac{0.84}{136.5} = 0.00615$$

$$\text{So } V = 0.00615\ Q^{0.712}$$



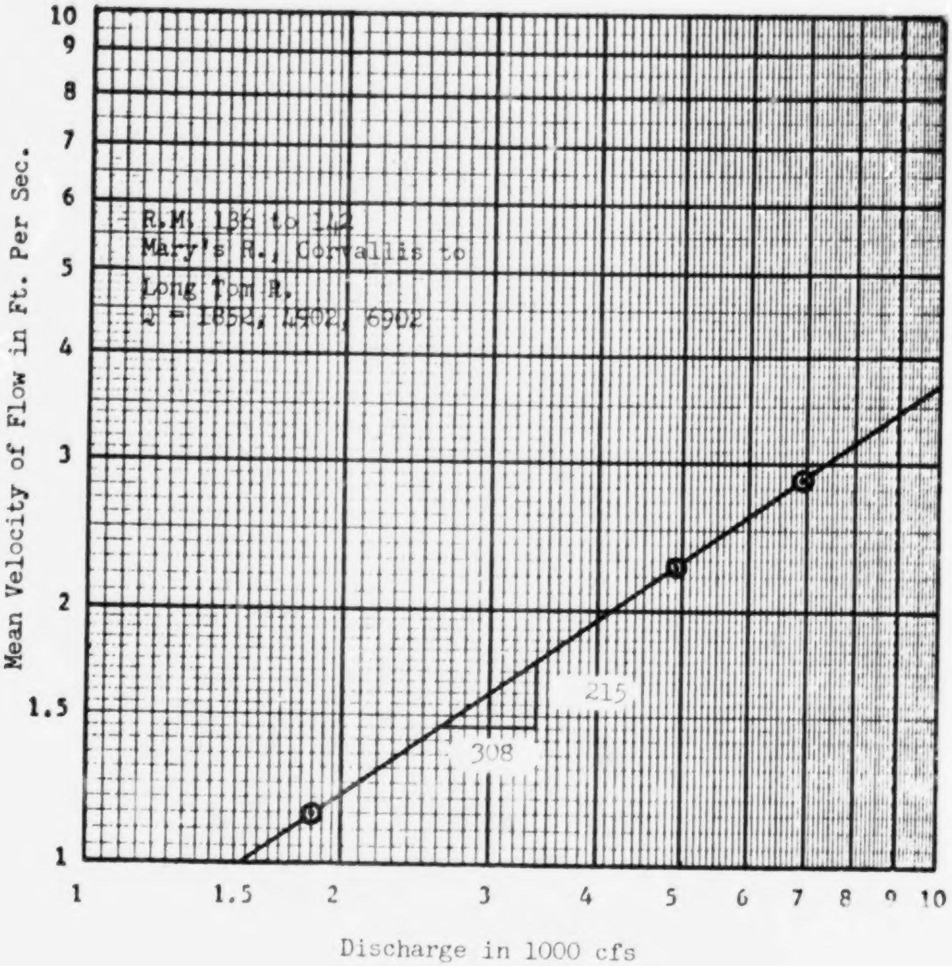
$$d = \frac{220}{376} = 0.585$$

@ $Q = 1500$, $V = 1.65$

$$1.65 = cQ^d = c1500^{0.585}$$

$$c = \frac{1.65}{72} = 0.0229$$

So $V = 0.0229\ Q^{\ 0.585}$

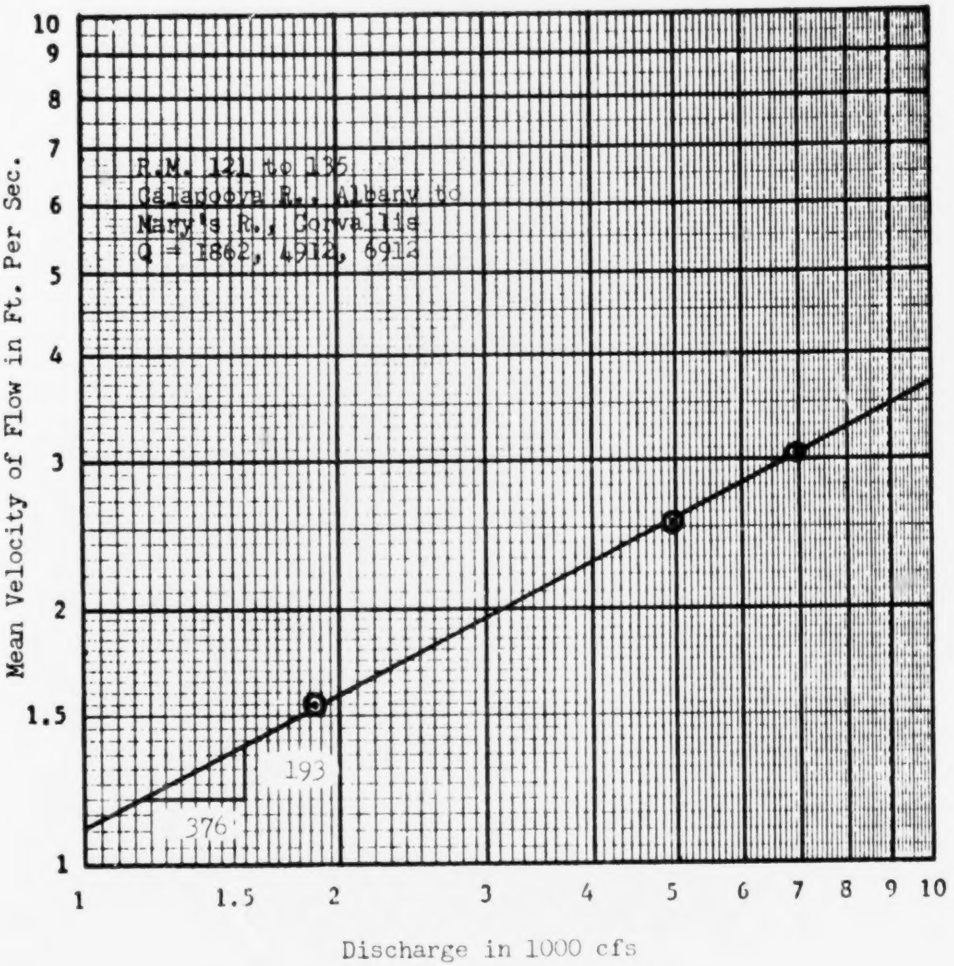


$$d = \frac{215}{308} = 0.698$$

$$@\ Q = 2200,\ V = 1.3$$

$$c = \frac{1.3}{216} = 0.00602$$

$$\text{So } V = 0.00602\ Q^{0.698}$$



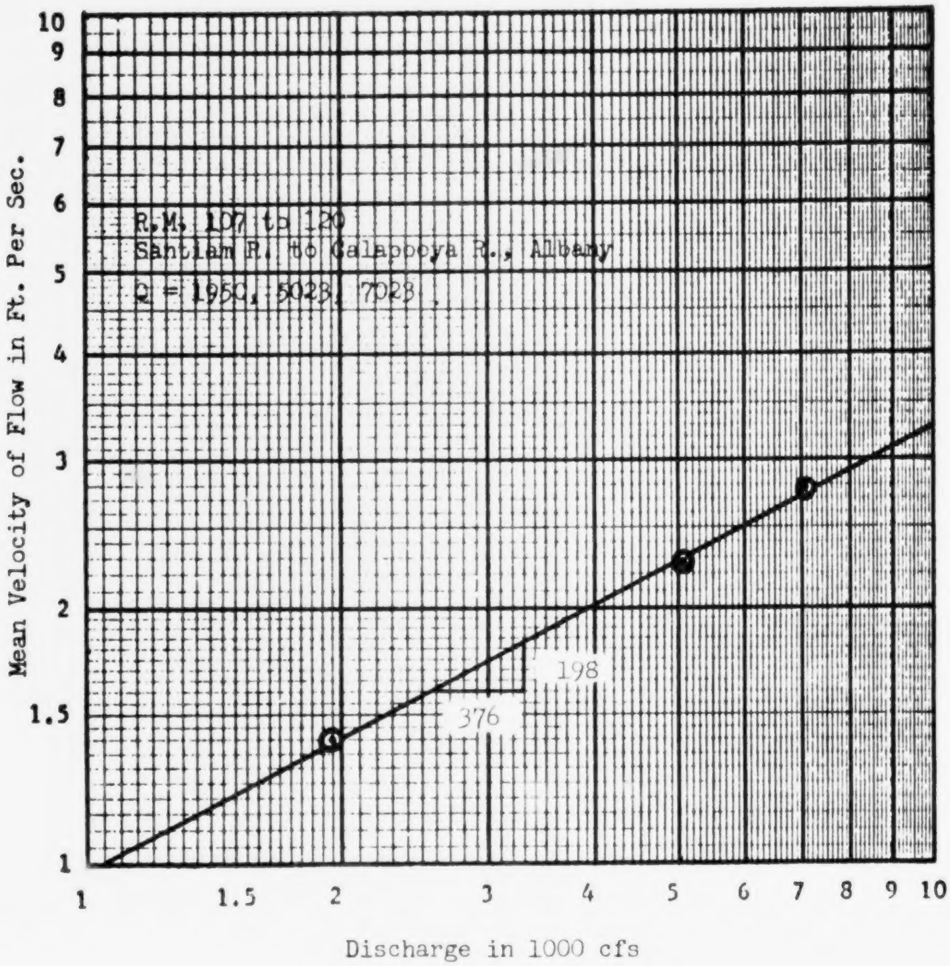
$$d = \frac{193}{376} = 0.513$$

@ Q = 2000, V = 1.6

$$1.6 = cQ^{d}$$

$$c = \frac{1.6}{49.2} = 0.03252$$

So $V = 0.03252\ Q^{0.513}$



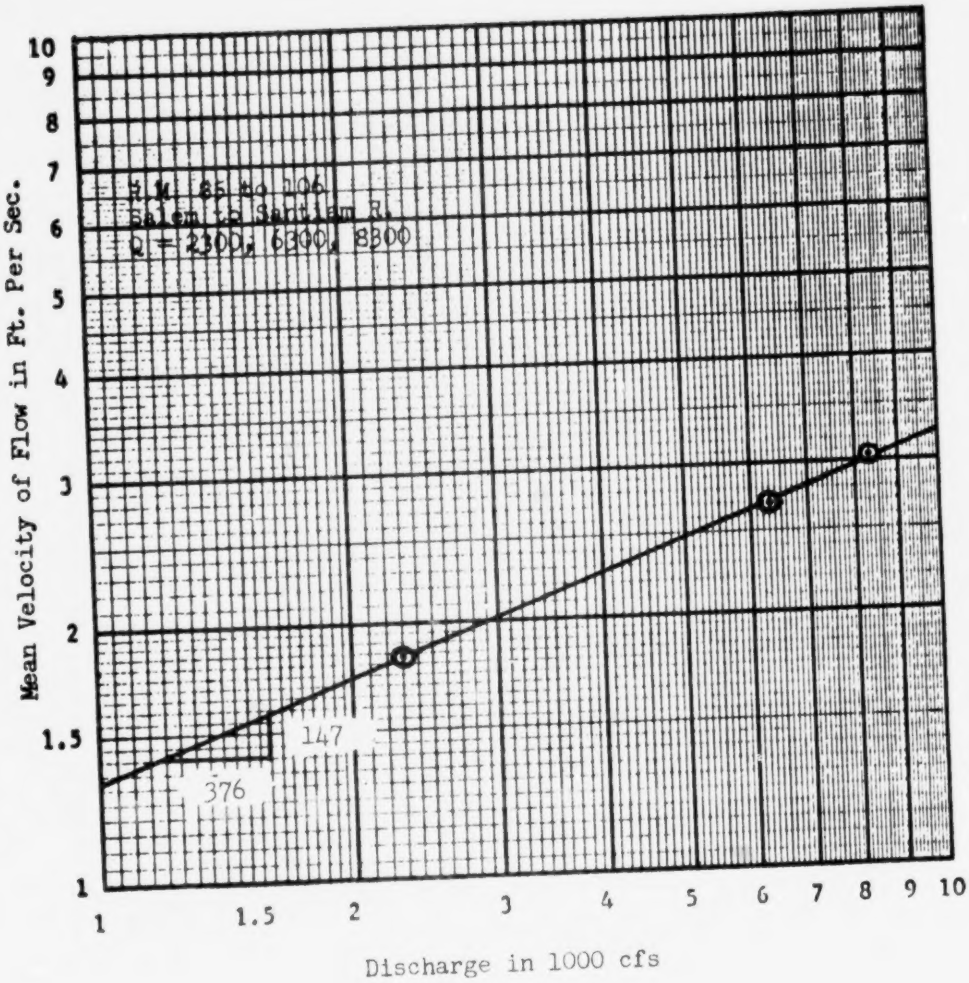
$$d = \frac{198}{376} = 0.527$$

@ Q = 1800, V = 135

$$1.35 = cQ^{d}$$

$$c = \frac{1.35}{52.1} = 0.0259$$

$$\text{So } V = 0.0259\, Q^{0.527}$$



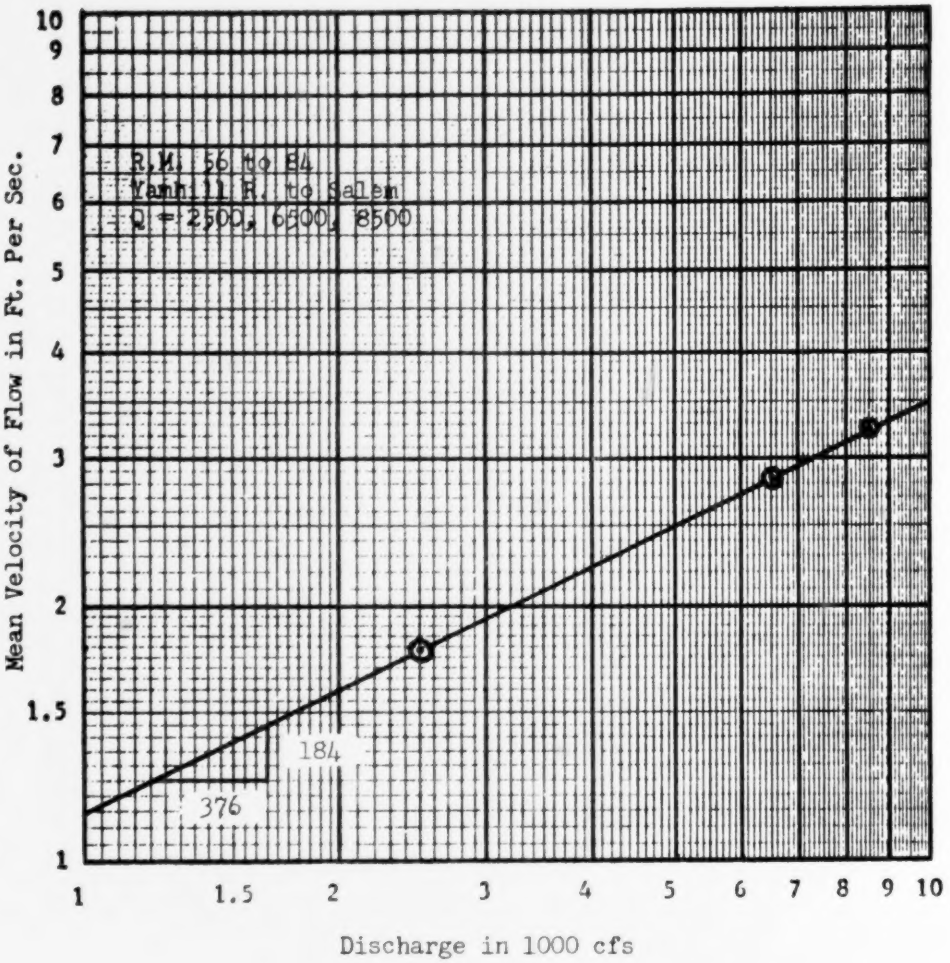
$$d = \frac{147}{376} = 0.391$$

@ $Q = 1500$, $V = 1.55$

$$1.55 = cQ^{d}$$

$$d = \frac{1.55}{17.5} = 0.08857$$

So $V = 0.08857\ Q^{0.391}$



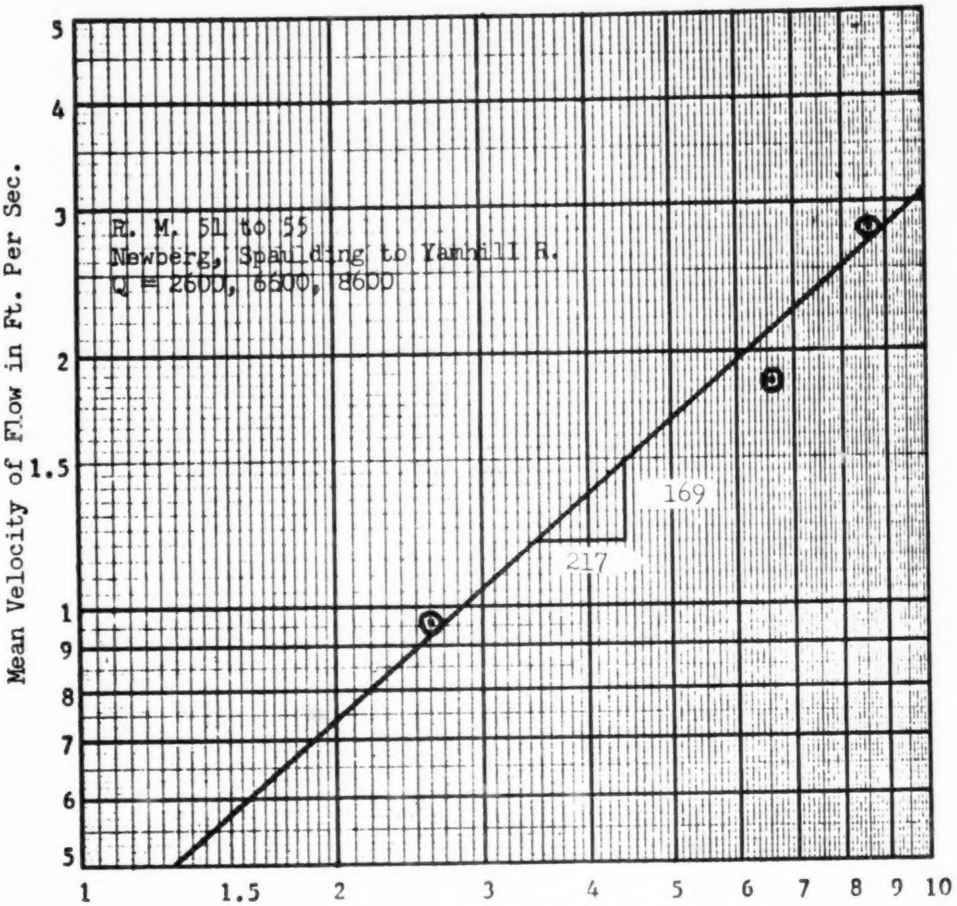
$$d = \frac{184}{376} = 0.489$$

$@\ Q = 2000,\ V = 1.6$

$$1.6 = cQ^{d}$$

$$c = \frac{1.6}{41.2} = 0.03883$$

So $V = 0.03883\ Q^{0.489}$



Discharge in 1000 cfs

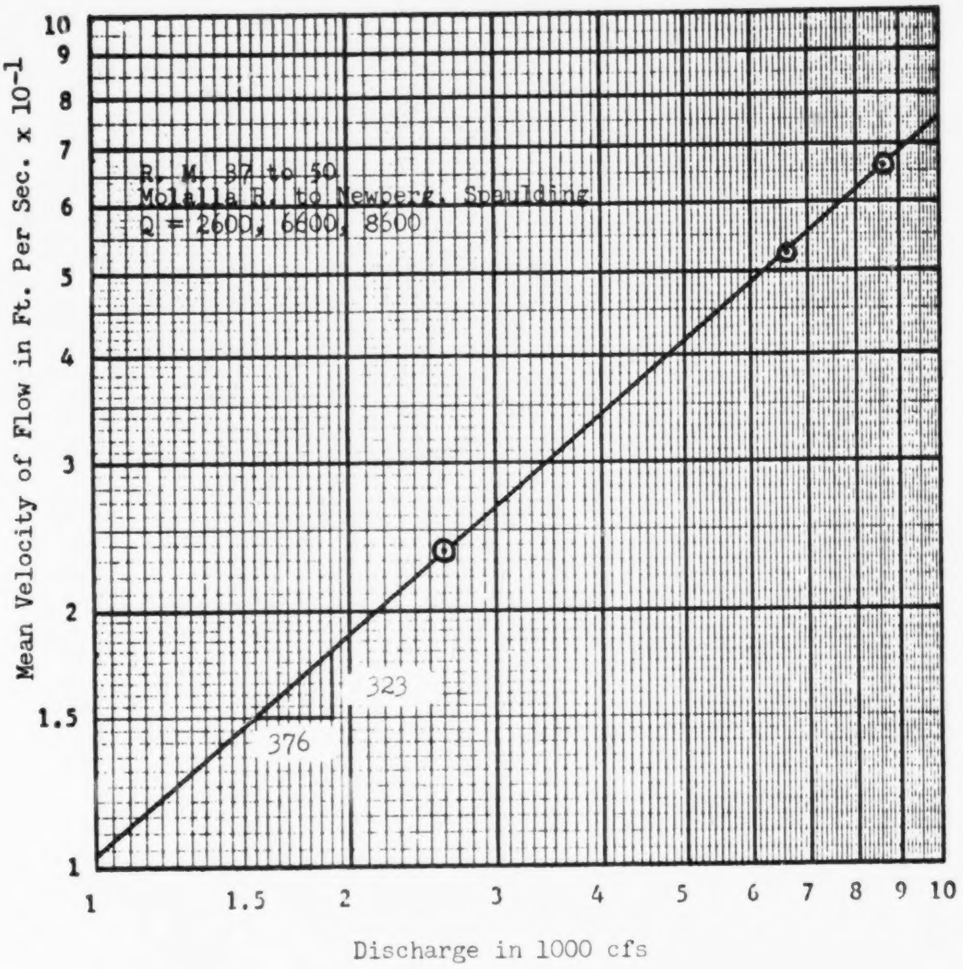
$$d = \frac{169}{217} = 0.779$$

@ Q = 6500, V = 2.0 ft./sec.

$$2.0 = cQ^{d}$$

$$c = \frac{2.0}{935} = 0.00214$$

So $V = 0.00214\ Q^{0.779}$



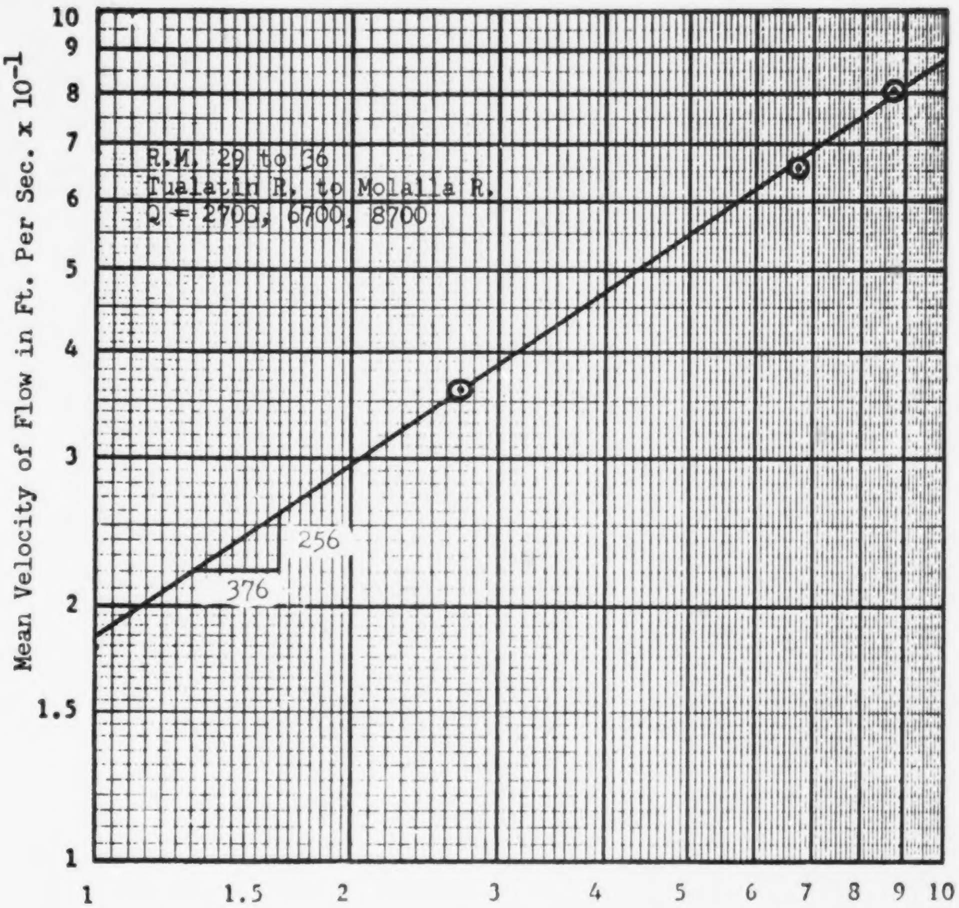
$$d = \frac{323}{376} = 0.859$$

@ $Q = 1350$, $V = 0.135$

$$0.135 = cQ^d$$

$$c = \frac{0.135}{490} = 0.0002755$$

So $V = 0.0002755\ Q^{0.859}$



Discharge in 1000 cfs

$$d = \frac{256}{376} = 0.681$$

@ $Q = 1250$, $V = 0.215$

$$0.215 = cQ^d$$

$$c = \frac{0.215}{129} = 0.001666$$

So $V = 0.001666\ Q^{0.681}$

Program Capabilities

This program is designed to analyze the dissolved oxygen resources of a complete drainage basin and to provide for automatic flow adjustment to satisfy minimum allowable dissolved oxygen requirements.

A river system comprised of one to three orders of streams and from one to sixty reaches can be included in a single set of data and analyzed in a few minutes. The program will evaluate the parameters of dissolved oxygen (DO), dissolved oxygen deficit, and BOD for the critical and end points of each reach for the flow which exists in the reach. If the DO existing in the reach is lower than the minimum allowable concentration, the computer will estimate the quantity of high-quality dilution water required to raise the DO concentration to the minimum allowable. (This assumes that there are some storage reservoirs in the basin which contain high-quality water.) A search for the required extra flow is then begun. This procedure begins with the reach where it was found that more flow was needed and proceeds upstream one reach at a time until a source of flow augmentation is located. If more than one source is available, an equal amount of flow will be taken from each source within the limits set by the investigator. Since increased flow results in greater depth and velocity, it will change the reaeration rate (k_2) and travel time in the reaches through which it moves, hence it is necessary to recalculate values for these reaches. In this manner, the computer proceeds back to the low DO reach to see if the new flow provides a satisfactory DO concentration within ± 0.1 ppm of the set minimum. If requirements are not yet satisfied, another search for flow augmentation will be made or, if more than the required amount of flow is now present, some will be "returned" to storage. This loop continues until requirements are satisfied or all applicable sources of augmentation have been exhausted. In either case, the short output format is printed at the completion of computations for each reach and the computer moves on to the next reach until all river reach calculations have been completed. When all reaches in the river system have been analyzed and minimum DO requirements satisfied or all sources of flow augmentation exhausted, the long (complete) output format is printed to show the final conditions in each reach.

At this point, the computer either stops or automatically proceeds to the next set of river data if one exists. This data may be for other conditions on the same river system or may be on a completely different drainage basin. The computer simply replaces the information in core storage with the new data and begins analysis of the new system. No limit is placed on the number of sets of data that may be processed in this manner. The computer stops when the last set of data is completed.

The detailed mechanics involved in the various functions performed by the program are shown in graphical form on the detailed flow chart presented as an aid in following the steps of solution.

The information furnished by the output from this program is felt to be especially useful in predicting river quality under future loading conditions. Both flow and waste loadings may be varied by manipulation of input data. Thus, it is possible to develop any hypothetical set of conditions for the river system by changing some of the input data. The computer can then analyze the dissolved oxygen resources of the system in a few minutes. Another useful function would be to study the effect of a heavy pollutional load introduced at various points in the river system.

Data Preparation for Oxygen Sag Program

The first considerations in applying the Oxygen Sag Program to a river system are: (1) the location of all the significant waste loading points; (2) the location of significant sources of inflow and diversions; (3) the development of a relatively accurate mileage index and accompanying travel times for the river system; and (4) location of all significant reservoirs, existing or planned. With this information, it is possible to divide the river into sufficient reaches to adequately define the problem. For this purpose a "reach" is defined as the points at which a significant change occurs, such as waste loading points, incoming tributaries, significant diversions or decided changes in slope or depth of the stream.

When the river system has been divided, the reaches are numbered and classified. The first reach on a stream would normally be located immediately below the most downstream reservoir on that stream. In the absence of reservoirs, the uppermost reach would be started at the furthest upstream point at which significant waste loading can be anticipated.

Reservoirs are not included as reaches unless sufficient data are available to define travel times and reaeration rates involved. These data are usually not available; if they are, a reservoir can be handled like any other reach.

The reach numbering system is designed such that the uppermost reach has the largest number (this number cannot be larger than 999), and numbering proceeds in descending order downstream to the smallest reach number (no smaller than 1) at the mouth. Figure 1 illustrates the numbering system. It is advisable to leave gaps in the numbering system to permit insertion of new reaches without disrupting the whole numbering system. The computer will begin with the largest reach number and proceed to the next smaller reach number in all cases when moving downstream. When moving upstream, the computer will begin with the reach presently being considered and proceed to the next higher number in all cases. In no case will the computer move more than one reach at a time.

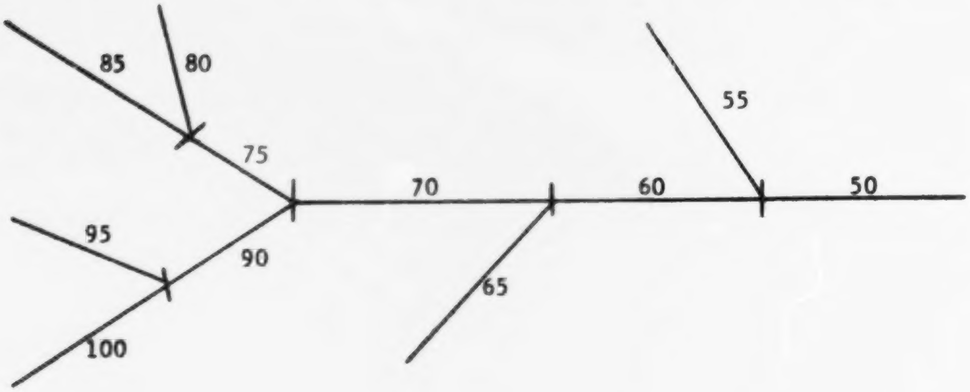


FIGURE 1
ILLUSTRATION OF REACH NUMBERING SYSTEM

Since this program will handle three orders of streams at once, there are three possible classifications. These are: branch, tributary, and main stem and are identified in the porgram by 1, 2, and 3, respectively. All branch reaches must join a tributary rather than the main stem. The program is designed to handle the case in which two tributaries come together to form the main stem. However, this situation can many times be avoided by judicious numbering and classifying of reaches. Figure 2 illustrates two possibilities for classifying the same stream system.

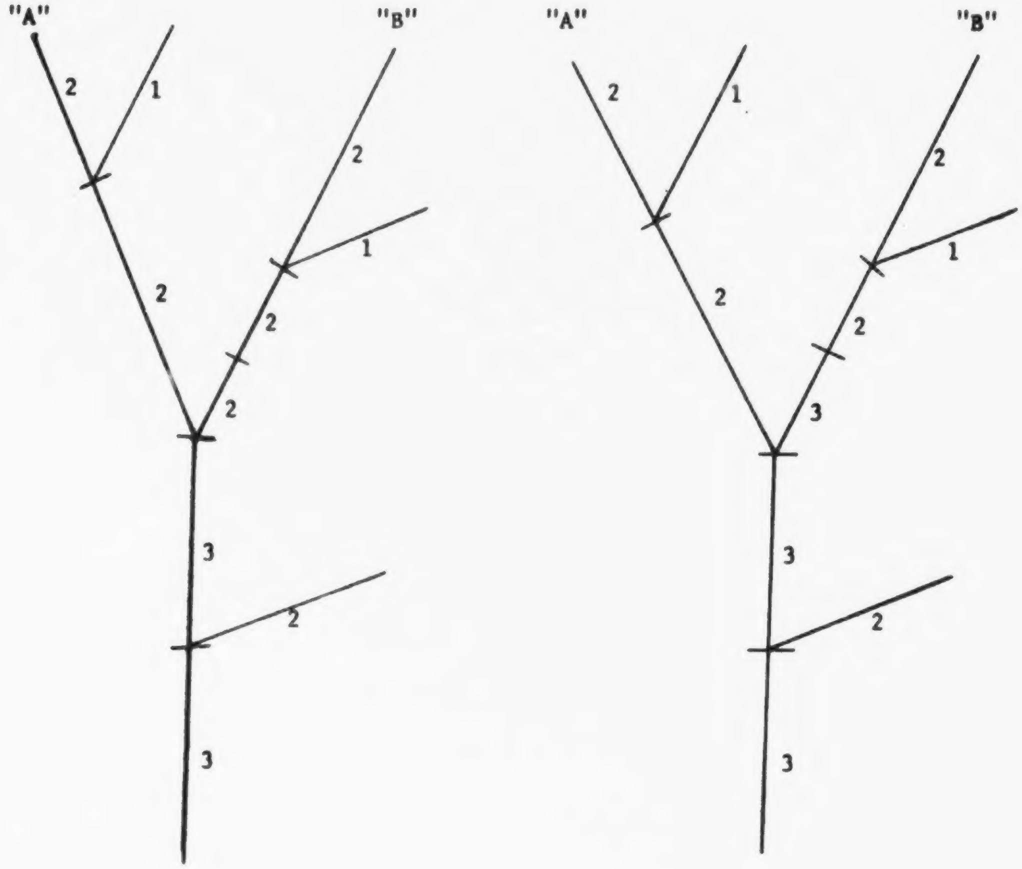


FIGURE 2
EXAMPLES OF VARIATION IN CLASSIFYING
THE REACHES OF A STREAM SYSTEM

The program must always start with a tributary reach and could start at either point "A" or point "B" for the classification of the river system as shown on the left in Figure 2 and only at point "B" for the classification on the right. Figure 3 illustrates how a stream could be classifiec for a main stem only system and still satisfy the requirements stated above.

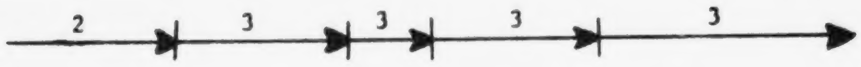


FIGURE 3
METHOD OF CLASSIFYING REACHES IN A
RIVER SYSTEM WITH A MAIN STEM ONLY

After numbering and classifying each reach, it is necessary to complete data sheets for the river system. There are two data sheets, each of which includes 25 columns of data for each river system. Sample data sheets are shown in Figures 4 and 5. Since there are only 80 columns on an IBM data card, it is necessary to use two cards. Each card contains the data from one row on one data sheet. The data sheets are laid out by the same format as the data cards for convenience of the card punch operators. The format of each item on the data sheets is indicated on the first row by the "x's" and decimal points. If no decimal point is shown, it would be located after the rightmost digit in that particular column. The leftmost column under each heading must be reserved for a positive or negative sign. If no sign is shown, the computer assumes a positive value.

A

Project ______ Branch ______ Sheet ______ of ______

Job ______ Date ______

Account No. ______ Study ______ Prepared By ______

RENO	DIGIT	RELEN	RIVMI	QMIN	QMAX	QI	QS	QOUT
1 2 3 4	5 6	7 8 9 10 11	12 13 14 15 16 17	18 19 20 21 22 23 24 25	26 27 28 29 30 31 32 33	34 35 36 37 38 39	40 41 42 43 44 45	46 47 48 49 50 51
XX	X	XX.X	XXX.X	XXXX	XXXX	XX.X	XX.XX	XX.X

E D P CARD DATA FORM

Sheet ______ of ______

Date

Prepared By

OX-SAG PROGRAM

B

DATA SHEET FOR FIRST DATA CARD

I		QS						QOUT						DOS				DI				DD				SLOAD																	
38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	NOTES
X.	X			X	X.	X	X				X	X.	X			X.	X			X.	X			X.	X					X	X	X											

CARD DATA FORM

A

Project

Job

Account No.

Branch

Study

Sheet _____ of _____

Date

Prepared By

TEMP	DOSAT	DOMIN	(BASE 'e') DOXK1	AK2	BK2	CVEL	DVEL
1 2 3 4 5	6 7 8 9 10	11 12 13 14	15 16 17 18 19 20	21 22 23 24 25 26 27 28	29 30 31 32 33 34 35 36	37 38 39 40 41 42 43 44	45 46 47 48 49 50
XX.X	XX.X	X.X	.XXX	.XXXXX	.XXXXX	.XXXXXX	.XXX

E D P CARD DATA FORM

Sheet ______ of ______

Date

Prepared By

OX-SAG PROGRAM

120 B

DATA SHEET FOR SECOND DATA CARD

CVEL								DVEL						BODI					BODD					BODS						BKLOD														
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	NOTES
		.X	X	X	X	X	X				.X	X	X				X	.X				X	.X				X	X	X				X	X	X									

P CARD DATA FORM

The first two headings on the data sheet for the first data card are "RENO" and "DIGIT" and are the reach number and classification number, respectively. The next heading, "RELEN," is the reach length to the nearest 1/10 of a mile. The fourth heading, "RIVMI," is the river miles from the mouth of the stream on which a particular reach is found to the upstream end of that reach. The river mile index starts with zero at the mouth of each stream and mileage increases upstream.

The fifth heading, "QMIN," is the minimum flow in cubic feet per second which would normally occur in any reach. However, this value will be zero for all except the uppermost reach on any given stream. This is done to aid the computer in searching for sources of flow augmentation. On the uppermost reach of each stream, QMIN will be the minimum release expected from a reservoir or, in the absence of a reservoir, it would be the mean flow in the reach. The next heading, "QMAX," is the maximum flow in cubic feet per second which could be expected in the reach during the study period. In all cases except immediately below a reservoir QMAX must be equal to the sum of all the flow coming into and diversion flow leaving the reach. (Incoming flow would be positive and outflow would be considered negative.) If there is a reservoir at the head of a reach, QMAX would be the maximum anticipated release from the reservoir during the study period. In this case, QMIN and QMAX would be substantially different.

The seventh heading, "QI," is the flow in cubic feet per second which enters the reach from ground water, small creeks and other miscellaneous sources which are either insignificant, in comparison with the total reach flow as to its particular source, or unidentifiable. This is normally inflow which enters between the upper and lower ends of the reach and can be measured, but cannot be accounted for by any other means. The next heading, "QS," is the flow of sewage or other wastes in cubic feet per second which enters a reach. Usually the inflow of waste between the midpoints of two adjoining reaches is assumed to enter at the head of the downstream reach. The ninth heading, "QOUT," is the diversion flow or flow taken out of the reach for some purpose. This is important because it will carry a proportionate amount of BOD and DO (both in pounds) with it, necessitating adjustment of these quantities. The diversion flow is always subtracted from the flow in the reach and will reduce QMAX, possibly making it smaller than for the previous reach. QMAX must be very close (approximately ± 2%) to the actual flow in the reach, unless this reach lies downstream from a reservoir which contains water intended for flow augmentation. Otherwise, the computer will interpret the difference between the actual flow in the reach (QSUM) and QMAX as a false source of flow augmentation.

The next three headings, "DOS," "DI," and "DD," are respectively: the DO of the incoming sewage or waste, the deficit of the incremental flow and the deficit of the dilution flow. All are in parts per million and are expressed to the nearest 1/10 of a part per million and are converted to pounds in the program. DOS and DI will have a value whenever there is any sewage or incremental flow entering the reach. DD will have a value only for uppermost reaches when QMIN has a value other than zero. (QMIN = QDIL, or dilution flow.) The last heading on the first data sheet, "SLOAD," is the load imposed by sludge deposits on the stream bottom or benthal demand in pounds per mile per day.

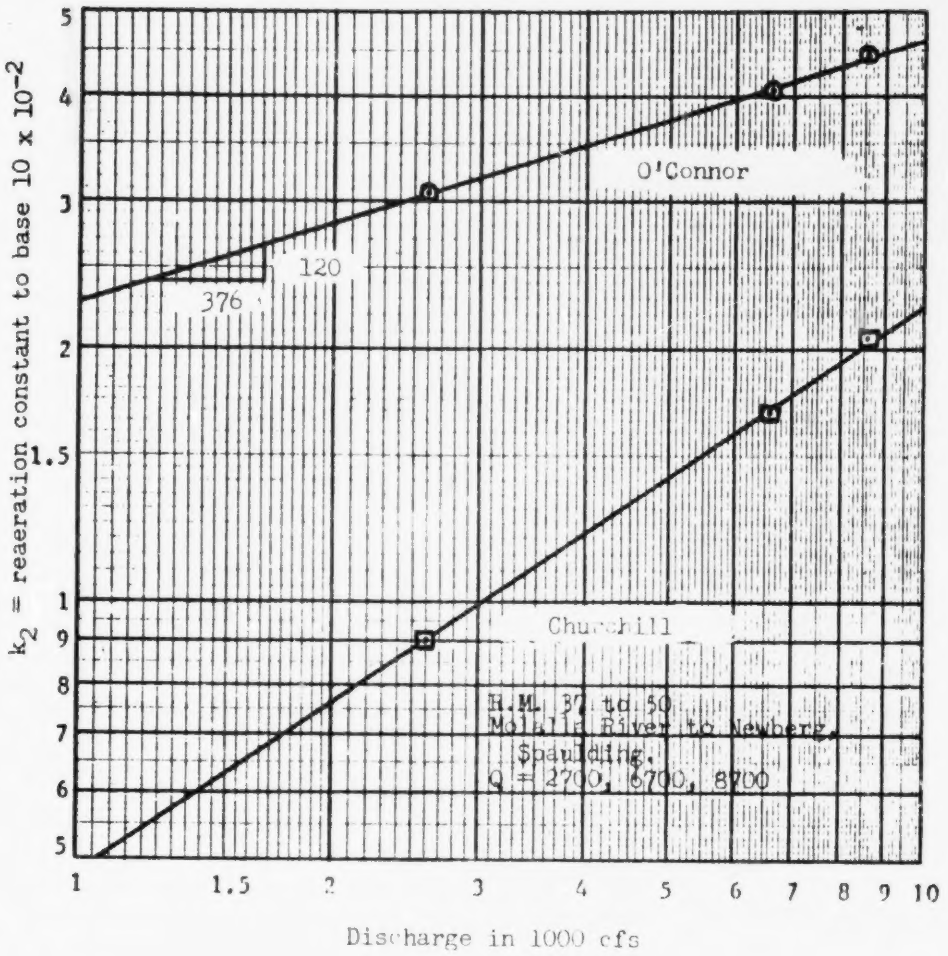
The first heading on the second data sheet, "TEMP," is simply the temperature in degrees Centigrade which prevails in the reach during the study period. The next two headings, "DOSAT" and "DOMIN," are respectively: the DO in parts per million at saturation for the temperature which exists in the reach, and the minimum DO in parts per million which it is desirable to maintain in this particular reach. DOMIN may vary from reach to reach and certainly from the headwaters of a stream to the lower extremities, depending on the intended use of the water. Both DOSAT and DOMIN are expressed to the nearest 1/10 part per million.

The fourth heading, "DOXK1," is the deoxygenation constant, K_1 (base e).

The next two headings, "AK2" and BK2," are a coefficient and an exponent of Q in the equation $k_2 = aQ^b$ (see Figure 6) which is used to evaluate the reaeration constant, k_2, in the program. It was necessary to relate k_2 to flow, since k_2 changes as the flow of a stream varies and produces different travel times and different degrees of turbulence. These factors are expressed as shown on the second data sheet. (k_2 is to base 10 and converted to base e in program.)

The headings, "CVEL" and "DVEL," are respectively: the coefficient and exponent of Q in the equation $VEL = cQ^d$ which is

FIGURE 6



$$b = \frac{120}{376} = 0.319$$

$$k_2 = 0.0275 \text{ @ } Q = 1950$$

$$0.0275 = aQ^b$$

$$a = \frac{0.0275}{11.2} = 0.002455$$

So $k_2 = 0.002455\ Q^{0.319}$

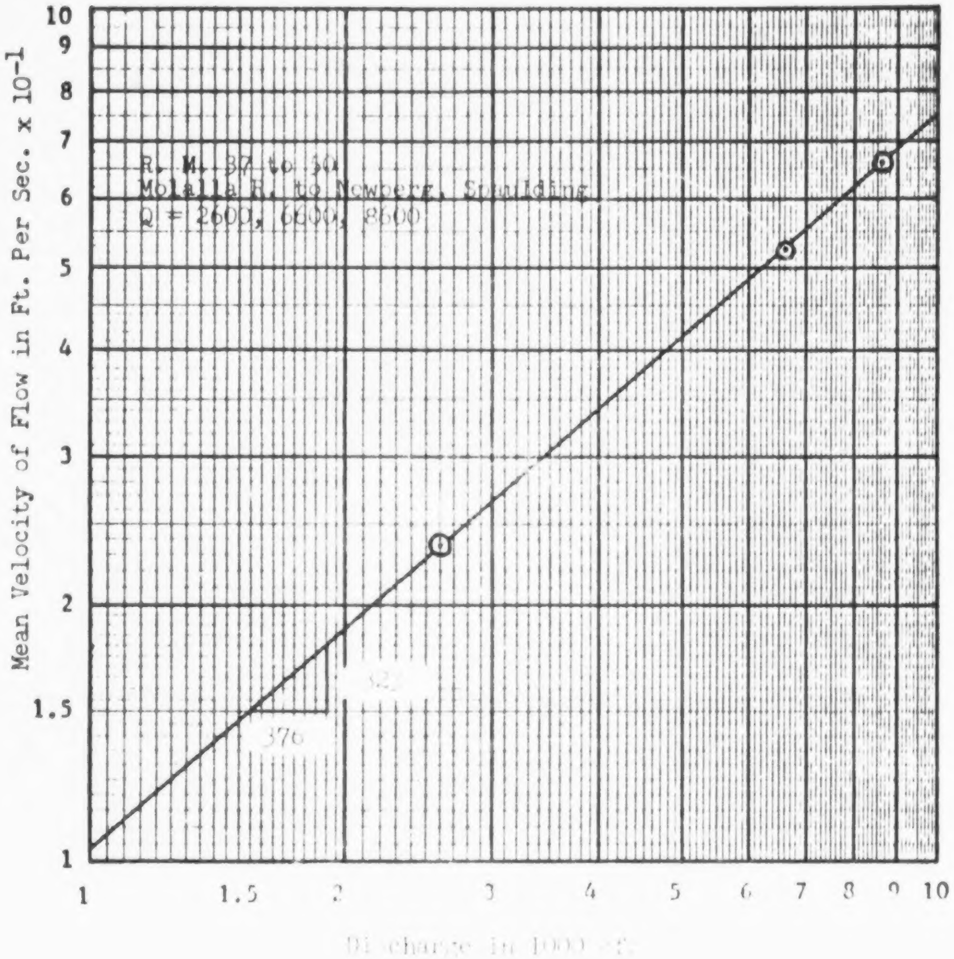
used in the program to relate velocity or travel time to flow (see Figure 7). These values are expressed as shown on the data sheet. (VEL is expressed as feet per second and converted to miles per hour in program before any print out of data.)

In cases in which data are lacking for calculation of either k_2 (k_2 is calculated by O'Connor's or some other acceptable equation) or VEL, it may be necessary to use an estimated value. This may be accomplished by letting the coefficient in either equation equal the estimated value and setting the exponent in either equation equal to zero. Since the exponentiation is performed first by the computer, this allows the estimate to appear as the final value. This precludes any variation of either k_2 or velocity for this particular reach.

The next three headings, BODI," "BODD," and "BODS," are respectively: the BOD of the incremental flow, the BOD of the dilution flow, and the BOD of the sewage or waste flow which enters the reach (all are ultimate BOD). These variables will have values whenever there are flows entering the reach which are classified as incremental, dilution, or sewage. BODI and BODD are expressed to the nearest 1/10 part per million and converted to pounds in the program. BODS is also in parts per million. One of these variables must always be greater than zero to avoid a division by zero in some of the computations in the program. It may sometimes be necessary to introduce a token load to avoid such a division by zero.

The last heading on the second data sheet, "BKLOD," is a catch-all for organic loads which may enter a stream. This term includes

FIGURE 7



$$d = \frac{323}{376} = 0.859$$

@ $Q = 1350$, $V = 0.135$

$$0.135 = cQ^d$$

$$c = \frac{0.135}{490} = 0.0002755$$

So $V = 0.000275\ Q^{0.859}$

such loads as land drainage, tree leaves which fall or blow into the river, possible algae die-offs, etc. It is expressed in pounds per mile per day.

Calculation of k_2 and Velocity

Forward velocity and k_2 are both dependent on the level of flow in a stream. In order to mathematically relate these parameters to flow, it is necessary to have a relatively complete knowledge of the physical characteristics of the river. The required physical data include: information which allows calculation of a mean depth, the velocity of forward flow or slope of the stream channel and a mileage index for the river system involved. Actual cross-sections of the river at a sufficient number of points to provide dependable mean values of depth, velocity, and surface width are probably the most valuable form of information. It is imperative that these cross-sections be obtained for at least two stages of flow and three or more levels would permit development of more valid relationships for k_2 vs flow and velocity vs flow. If cross-section data are not available, it is necessary to know the slope of the stream channel and the mean depth of the stream for at least two and preferably more levels of flow. With these data, it is possible to calculate a value for k_2 at each level of flow. The following equations are some of the more common ones used in k_2 calculations.

$$k_2 \text{ @ } 20^{o}\text{C} = 480 \frac{D_L^{1/2} S^{1/4}}{H^{5/4}}$$

O'Connor
shallow streams
(Chezy C < 17)

$$k_2 \text{ @ } 20^{o}\text{C} = \frac{(D_L U)^{1/2}}{2.31 H^{3/2}}$$

O'Connor
deep streams
(Chezy C > 17)

In which:

k_2 is to base 10.

D_L = coefficient of diffusion of oxygen into water in square feet/day.

U = velocity of forward flow in feet/day.

H = depth of flow in feet.

S = slope of channel in fet per foot.

k_2 at 20°C = $5.026\ V^{0.969}\ R^{-1.673}$ Churchill

k_2 at 20°C = $1.447\ V^{1.049}\ R^{-2.262}\ f^{-0.823}$ Churchill

k_2 at 20°C = $0.041\ V^{2.361}\ R^{-2.753}\ S^{-0.669}$ Churchill

k_2 at 20°C = $44.55\ R^{-1.297}\ S^{0.230}$ Churchill

In which:

V = forward velocity in feet per second.

R = mean depth in feet.

S = slope of energy gradient.

f = friction factor or resistance coefficient.

When k_2 had been evaluated for the various levels of flow in each reach, it is plotted versus flow on log-log paper. The points generally form a straight line (see Figure 6), which can be described by an equation of the form:

$$k_2 = aQ^b$$

Linearlizing this equation produces the form:

$$\log k_2 = b \log Q + a$$

which is analogous to the equation of a straight line:

$$y = mx + b$$

Where:

k_2 = rearation factor.

Q = flow in cubic feet/second.

b = arithmetic slope of line.

a = intercept on ordinate when log Q = 0 or Q = 1.

This equation relates k_2 to flow for use in the program.

The units of a and k_2 are 1/days and the units of Q are always cfs. The exponent b has no dimensions since it is the slope of the straight line in feet per foot. As a result, this equation is not dimensionally homogeneous. However, it was felt that so long as the user realizes that k_2 and Q have dimensions as stated above, and that this is an empirical equation to be used in a digital computer which does not consider dimensions, it would be unnecessary to develop an equation which is dimensionally homogeneous.

If velocities are known for two or more levels of flow, it is possible to plot velocity vs flow on log-log paper (see Figure 7) and generally obtain a straight line. The equation of this line is developed in the same manner as the equation for k_2. The resulting relationship is:

$$VEL = cQ^d$$

The units of Q are always cfs. The units of VEL and c are feet per second and d is dimensionless. Again, this is an empirical equation which is not dimensionally homogeneous and the explanation given for the k_2 equation also applies here.

The coefficients and exponents in these equations can be rather easily evaluated as shown in Figure 6. The exponent "b" is simply the arithmetic slope of the line. After obtaining a value for the slope of the line, it is necessary to choose a value of both k_2 and Q for some point on the line. Then Q is raised to the b power. This number is divided into k_2 to obtain a value for a. (See Figure 6 for sample calculation.)

The constants in the velocity relationship are evaluated in the same manner (see Figure 7).

Output Data

This program uses two different formats for printing output data. The first or short format is used to print intermediate output data which is printed at the completion of the solution of each reach. This format includes: the reach number (RENO), the reach classification number (DIGIT), the flow necessary to satisfy minimum requirements for this reach considering only upstream loadings (QDUP), the velocity of forward flow in this reach (VEL),and the dissolved oxygen concentration in parts per million at the critical point in this reach (DOCPPM). This data can be used to see the effect of the additional flow increments when added in cases in which flow augmentation is required. It also shows the original conditions which existed in any particular reach so long as minimum specifications are satisfied. The following page is an example of a short format output data sheet for a case in which flow augmentation was necessary. It shows how downstream requirements may cause increases in the flow through some of the upper reaches.

The long output format is used only for printing the final solution for the complete river system. This format prints 15

MODEL RIVER SYSTEM
SHORT FORMAT
OUTPUT DATA SHEET

RENO	DIGIT	QDUP	VEL	DOCPPM
105.	2.	1001.	1.59	10.48
103.	1.	40.	1.59	10.47
101.	2.	992.	1.59	10.48
96.	2.	551.	.72	9.48
95.	2.	651.	.77	1.87
105.	2.	1135.	1.59	10.49
103.	1.	40.	1.59	10.47
101.	2.	1056.	1.59	10.48
96.	2.	551.	.72	9.48
95.	2.	651.	.77	1.87
89.	3.	1738.	.93	7.03
105.	2.	1310.	1.59	10.49
103.	1.	40.	1.59	10.47
101.	2.	1232.	1.59	10.48
96.	2.	551.	.72	9.48
95.	2.	651.	.77	1.87
89.	3.	1914.	.98	7.35
88.	3.	1945.	.99	7.20
105.	2.	1760.	1.59	10.49
103.	1.	40.	1.59	10.47
101.	2.	1681.	1.59	10.49
96.	2.	551.	.72	9.48
95.	2.	651.	.77	1.87
89.	3.	2363.	1.10	7.95
88.	3.	2394.	1.11	7.75
87.	3.	2425.	1.12	7.77
86.	3.	2456.	1.13	7.84
85.	3.	2487.	1.14	8.04

LONG FORMAT OUTPUT DATA FOR MODEL RIVER SYSTEM

```
RENO  DIGIT  QSUM   DOCPPM  DCP   DOEND  DENDPM  BODEND  TIMEC  TEND   CRMILE  RELEN  RIVMI  REK2     TEMP

105.   2.    1760.  10.49   0.00  10.49  0.00     0.0    0.000   .182   0.0     7.0    18.0  4.18341  13.4
103.   1.      40.  10.47    .02  10.49  0.00     0.0    0.000   .187   0.0     7.2     7.2  8.67636  13.4
101.   2.    1681.  10.49   0.00  10.49  0.00     0.0    0.000   .286   0.0    11.0    11.0  4.18341  13.4
 96.   2.     551.   9.48    .01   9.49  0.00     0.0    0.000   .462   0.0     8.0    28.0  5.85816  18.0
 95.   2.     651.   1.87   7.62   4.02  5.47    30.9     .423  1.071   7.9    20.0    20.0  4.95033  18.0
 89.   3.    2363.   7.95   2.04   7.95  2.04     6.9     .412   .412  11.0    11.0   187.0  1.18030  16.0
 88.   3.    2394.   7.75   2.24   7.75  2.24     5.5     .409   .409  11.0    11.0   176.0  1.17948  16.0
 87.   3.    2425.   7.77   2.22   7.82  2.17     4.4     .096   .406   2.6    11.0   165.0  1.17868  16.0
 86.   3.    2456.   7.84   2.15   8.02  1.97     3.6    0.000   .403   0.0    11.0   154.0  1.17788  16.0
 85.   3.    2487.   8.04   1.95   8.26  1.73     2.9    0.000   .400   0.0    11.0   143.0  1.17709  16.0


      RENO  HUNT  DIGIT  TIMEC  DOCPPM  KNT  KOUNT  N1  N2  N3  N4  LFLAG  QREQD  QOVER  QSUM

      105.  87.   2.     0.000  10.494  1    2      0   0   0   0   1      1760.  1807.  1760.
```

items for each reach (see Page 131). From left to right across this data sheet, the headings are: "RENO" (reach number), "DIGIT" classification number), "QSUM" (flow in reach for final solution of river system), "DOCPPM" (dissolved oxygen concentration in ppm at the critical point in reach), "DCPPM" (deficit in ppm at the critical point in the reach), "DOEND" (dissolved oxygen concentration in ppm at end of reach), "DENDPM" (deficit in ppm at end of reach), "BODEND" (BOD in ppm at end or reach), "TIMEC" (time in days to critical point in reach), "TEND" (time in days to end of reach), "RELEN" (reach length in miles), "RIVMI" (the river mile from mouth of this particular stream to head of reach), "REK2" (reaeration constant k_2, base e), and "TEMP" (the temperature in degrees that prevails in this reach). The long format output data sheet shown on Page 131. for the same model river system as the short format sheet on Page 130. By comparing values on these two sheets, it is seen that some of the values are the same and some decidedly different. As an example, it is seen that QSUM is the same as QDUP as it last appears for any reach in some cases and as it first appears in other cases. This indicates whether flow augmentation was available and used. If QDUP as it first appears for any given reach is the same as QSUM, no flow augmentation was available or none was needed.

The DO, deficit, and BOD data are self-explanatory. TIMEC may be compared with TEND and CRMILE compared with RELEN to show where the sags occurred. If TIMEC is 0, the whole reach is recovering and the highest deficit occurs at the head of the reach. If TIMEC has a value but is smaller than TEND, the lowest point in the sag occurs somewhere within the reach. If TIMEC is the same as TEND, the DO profile is declining throughout the reach and the greatest deficit occurs at the downstream end of the reach.

The list of new headings across the bottom of the sheet is an error-finding routine which was used in developing the program. It is valuable in determining what caused the computer to stop when errors are present and is printed in all cases before a complete stop is made.

Data Check Program

This program was developed for use in checking input data for OX-SAG PROGRAM. This is necessary to guard against feeding the computer data which is inconsistent and would cause computations to be stopped before completion of the river system or would result in erroneous answers on the output sheets. The program is rather simple in that it merely compares two numbers in most cases and prints only if the untried number is incorrect. In the case of flow, a running account is kept and comparisons of QMAX and QMIN are made for each reach to avoid indicating false sources of flow augmentation. There will be no printing of information unless incorrect input data are located.

This program will be fed into the computer and followed by as many data decks as desired. The provision in this program for accepting a new deck of data cards after completing a previous deck is the same as in the OX-SAG PROGRAM so this also serves as a check on that feature. This program should be used with all data decks before they are fed into the OX-SAG PROGRAM.

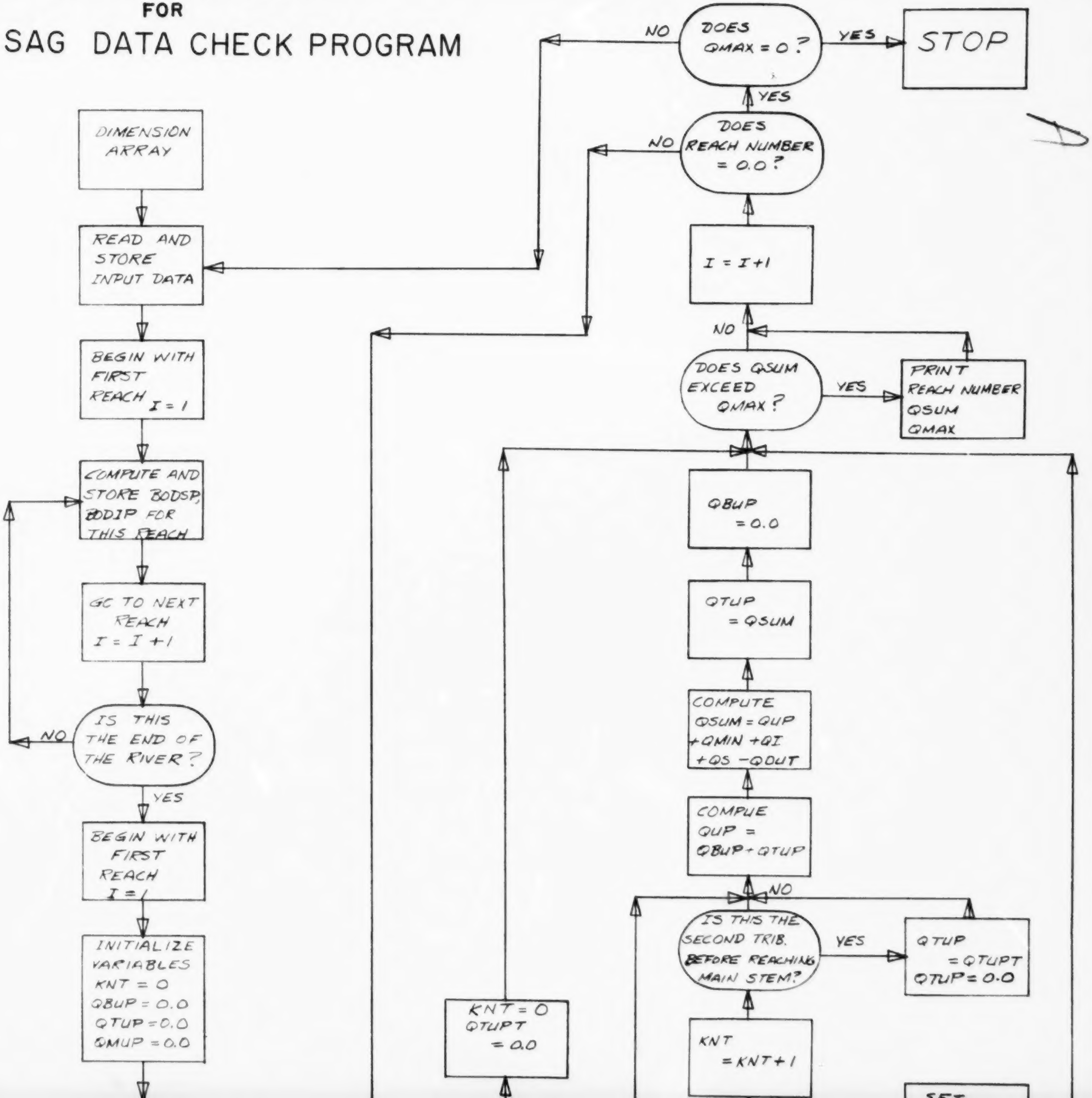
```
C       DATA CHECK PROGRAM FOR OX-SAG PROGRAM
      1 FORMAT(F4.0,F2.0,F5.1,F6.1,2F8.0,F6.1,F6.2,F6.1,3F4.1,F7.0/
     22F5.1,F4.1,F6.3,2F8.5,F8.6,F6.3,2F5.1,2F6.0)
        DIMENSION A(46,30)
     10 READ 2,K
      2 FORMAT(13)
        DO 3 I = 1,K
      3 READ 1,A(I,1),A(I,2),A(I,3),AI,4),A(I,5),A(I,6),A(I,7),A(I,8),
     2A(I,9),A(I,10),A(I,11),A(I,12),A(I,13),A(I,14),A(I,15),A(I,16),
     3A(I,17),A(I,18),A(I,19),A(I,20),A(I,21),A(I,22),A(I,23),A(I,24),
     4A(I,25)
        I = 1
      4 BODSP = 5.39 * A(I,24) * A(I,8)
        A(I,26) = BODSP
        BODIP = 5.39 * A(I,22) * A(I,7)
        A(I,28) = BODIP
        I = I + 1
        IF(1.- A(I,1))4,4,5
      5 I = 1
        KNT = 0
        QBUP = 0.0
        QTUP = 0.0
        QMUP = 0.0
     98 IF(1 - I)6,7,77
      6 IF(A(I-1,1) - A(I,1))21,21,8
      7 IF(999. - A(I,1))21,8,8
```

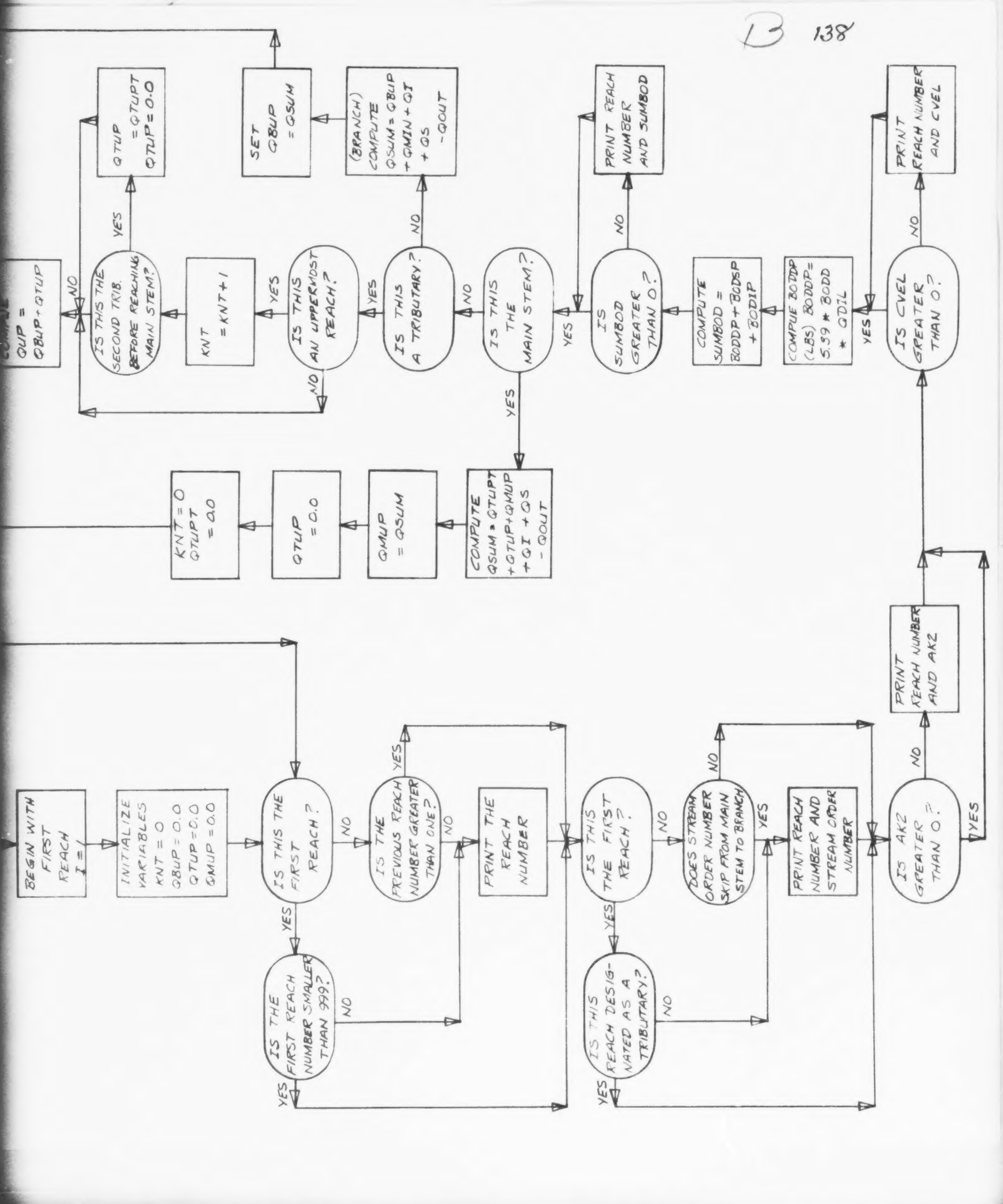
```
77 STOP

20 FORMAT(4HRENO,F6.0)

21 PRINT 20, A(I,1)

 8 IF(1 - I)9,11,9

 9 IF(ABSF(A(I-1,2) - A(I,2)) - 1.0)24,24,22

11 IF(A(I,2) - 2.0)22,24,22

23 FORMAT(4HRENO,F6.0,3X,5HDIGIT,F4.0)

22 PRINT 23, A(I,1),A(I,2)

24 IF(A(I,18))25,25,27

26 FORMAT(4HRENO,3X,F4.0,3X,3HAK2,3X,F8.5)

25 PRINT 26, A(I,1),A(I,18)

27 IF(A(I,20))28,28,30

29 FORMAT(4HRENO,3X,F4.0,3X,4HCVEL,3X,F8.6)

30 BODDP = 5.39 * A(I,23) * A(I,5)

   SUMBOD = BODDP + A(I,26) + A(I,28)

   IF(SUMBOD)31,31,33

32 FORMAT(4HRENO,3X,F4.0,3X,6HSUMBOD,3X,F8.0)

31 PRINT 32, A(I,1), SUBBOD

33 IF(2.0 - A(I,2))34,35,35

35 IF(1.0 - A(I,2))36,40,77

36 IF(1.0 - A(I,5))37,39,39

37 KNT = KNT + 1

   IF(2 - KNT)77,38,39

38 QTUPT = QTUP

   QTUP = 0.0
```

```
39 QUP = QBUP + QTUP
   QSUM = QUP + A(I,5) + A(I,7) + A(I,8) - A(I,9)
   QTUP = QSUM
   QBUP = 0.0
   GO to 42
40 QSUM= QBUP + A(I,5) + A(I,7) + A(I,7) +A(I,8) - A(I,9)
41 QBUP = QSUM
   GO TO 42
34 QSUM = QTUPT + QTUP + QMUP + A(I,7) + A(I,8) - A(I,9)
   QMUP = QSUM
   QTUP = 0.0
   KNT = 0
42 IF(1.02 * A(I,6) - QSUM)44,44,45
43 FORMAT(4HRENO, 2X,F4.0,2X,4HQSUM,F8.0,2X,4HQMAX,F8.0)
44 PRINT 43,A(I,1), QSUM, A(I,6)
45 I = I + 1
   IF(A(I,1))77,46,98
46 IF(AI,6))77,77,10
   END
```

LOGIC DIAGRAM
FOR
OX-SAG DATA CHECK PROGRAM

A


DIMENSION ARRAY
READ AND STORE INPUT DATA
BEGIN WITH FIRST REACH I = 1
COMPUTE AND STORE BODSP, BODIP FOR THIS REACH
GC TO NEXT REACH I = I + 1
IS THIS THE END OF THE RIVER?
NO
YES
BEGIN WITH FIRST REACH I = 1
INITIALIZE VARIABLES KNT = 0 QBUP = 0.0 QTUP = 0.0 QMUP = 0.0
KNT = 0 QTUPT = 0.0
DOES QMAX = 0?
YES
STOP
NO
DOES REACH NUMBER = 0.0?
YES
NO
I = I+1
NO
DOES QSUM EXCEED QMAX?
YES
PRINT REACH NUMBER QSUM QMAX
QBUP = 0.0
QTUP = QSUM
COMPUTE QSUM = QUP +QMIN +QI +QS -QOUT
COMPUE QUP = QBUP+QTUP
NO
IS THIS THE SECOND TRIB. BEFORE REACHING MAIN STEM?
YES
QTUP = QTUPT QTUP = 0.0
KNT = KNT+1
SET


BEGIN WITH FIRST REACH I = 1
INITIALIZE VARIABLES KNT = 0 QBUP = 0.0 QTUP = 0.0 QMUP = 0.0
IS THIS THE FIRST REACH?
YES
NO
IS THE FIRST REACH NUMBER SMALLER THAN 999?
IS THE PREVIOUS REACH NUMBER GREATER THAN ONE?
PRINT THE REACH NUMBER
IS THIS THE FIRST REACH?
IS THIS REACH DESIGNATED AS A TRIBUTARY?
DOES STREAM ORDER NUMBER SKIP FROM MAIN STEM TO BRANCH
PRINT REACH NUMBER AND STREAM ORDER NUMBER
IS AK2 GREATER THAN 0?
PRINT REACH NUMBER AND AK2
IS CVEL GREATER THAN 0?
PRINT REACH NUMBER AND CVEL
COMPUE BODDP (LBS) BODDP = 5.39 * BODD * QDIL
COMPUTE SUMBOD = BODDP + BODSP + BODIP
IS SUMBOD GREATER THAN 0?
PRINT REACH NUMBER AND SUMBOD
IS THIS THE MAIN STEM?
COMPUTE QSUM = QTUPT + QTUP + QMUP + QI + QS - QOUT
QMUP = QSUM
QTUP = 0.0
KNT = 0 QTUPT = 0.0
IS THIS A TRIBUTARY?
(BRANCH) COMPUTE QSUM = QBUP + QMIN + QI + QS - QOUT
SET QBUP = QSUM
IS THIS AN UPPERMOST REACH?
KNT = KNT + 1
IS THIS THE SECOND TRIB. BEFORE REACHING MAIN STEM?
QTUP = QTUPT QTUP = 0.0
COMPUTE QUP = QBUP + QTUP

A

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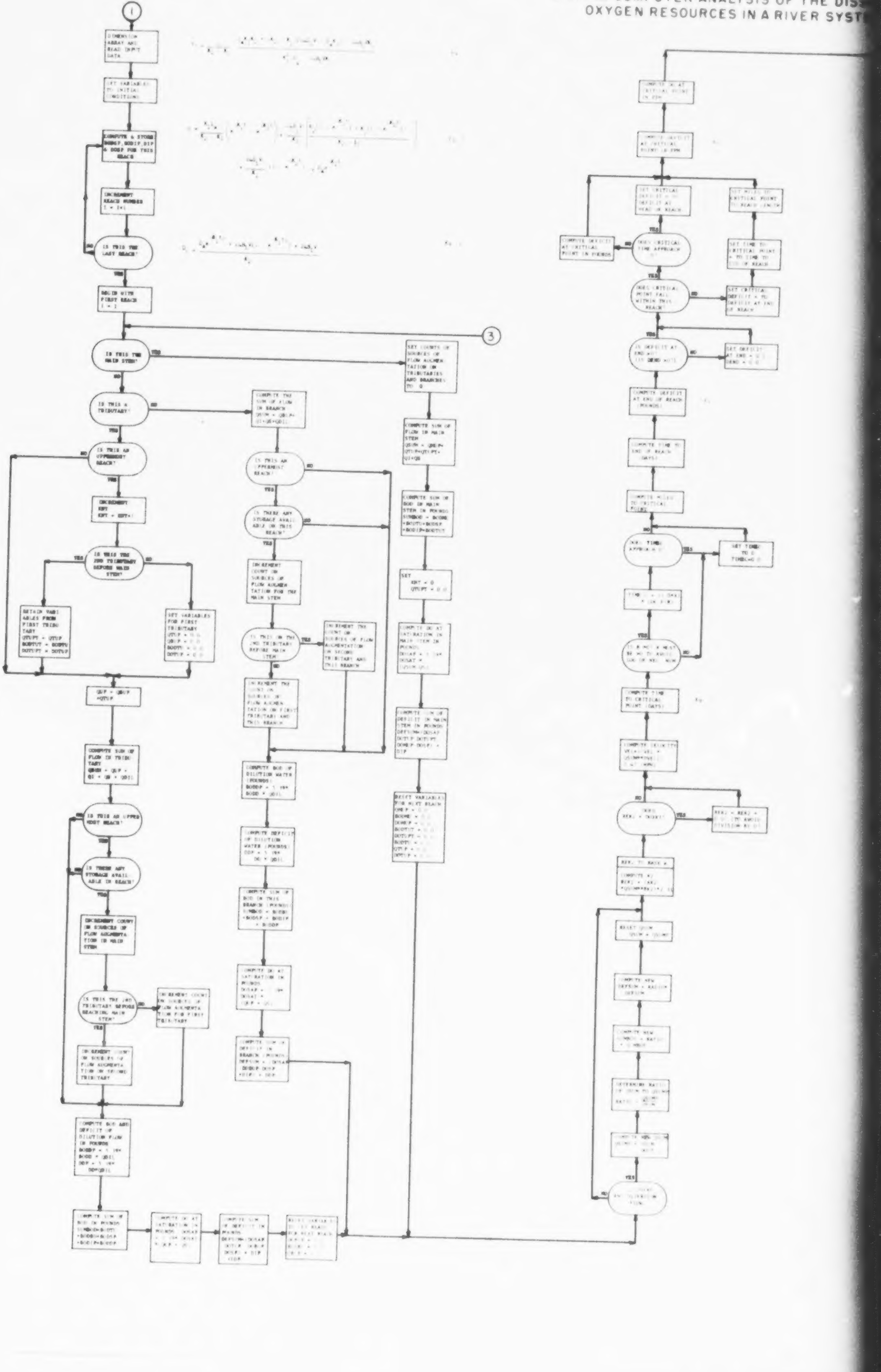
DETAILED LOGIC DIAG

F O R

DIGITAL COMPUTER ANALYSIS OF THE DISS
OXYGEN RESOURCES IN A RIVER SYST


1
DIMENSION ARRAY AND READ INPUT DATA
SET VARIABLES TO INITIAL CONDITIONS
COMPUTE & STORE BODSP, BODIP, DIP & DOSP FOR THIS REACH
INCREMENT REACH NUMBER I = I+1
IS THIS THE LAST REACH?
NO
YES
BEGIN WITH FIRST REACH I = 1
3
IS THIS THE MAIN STEM?
YES
NO
SET COUNTS OF SOURCES OF FLOW AUGMENTATION ON TRIBUTARIES AND BRANCHES TO 0
IS THIS A TRIBUTARY?
NO
YES
COMPUTE THE SUM OF FLOW IN BRANCH QSUM = QBUP+ QI+QS+QDIL
COMPUTE SUM OF FLOW IN MAIN STEM QSUM = QBUP+ QTUP+QTUPT+ QI+QS
IS THIS AN UPPERMOST REACH?
INCREMENT KNT KNT = KNT+1
IS THIS AN UPPERMOST REACH?
IS THERE ANY STORAGE AVAILABLE ON THIS REACH?
COMPUTE SUM OF BOD IN MAIN STEM IN POUNDS SUMBOD = BODBE +BODTU+BODSP +BODIP+BODTUT
IS THIS THE 2ND TRIBUTARY BEFORE MAIN STEM?
INCREMENT COUNT ON SOURCES OF FLOW AUGMENTATION FOR THE MAIN STEM
SET KNT = 0 QTUPT = 0.0
RETAIN VARIABLES FROM FIRST TRIBUTARY QTUPT = QTUP BODTUT = BODTU DOTUPT = DOTUP
SET VARIABLES FOR FIRST TRIBUTARY QTUP = 0.0 QBUP = 0.0 BODTU = 0.0 DOTUP = 0.0
IS THIS ON THE 2ND TRIBUTARY BEFORE MAIN STEM?
INCREMENT THE COUNT OF SOURCES OF FLOW AUGMENTATION ON SECOND TRIBUTARY AND THIS BRANCH
COMPUTE DO AT SATURATION IN MAIN STEM IN POUNDS DOSAP = 5.39* DOSAT * QSUM
INCREMENT THE COUNT ON SOURCES OF FLOW AUGMENTATION ON FIRST TRIBUTARY AND THIS BRANCH
QUP = QBUP +QTUP
COMPUTE SUM OF DEFICIT IN MAIN STEM IN POUNDS DEFSUM=(DOSAP DOTUP DOTUPT DOBEP DOSP) + DIP
COMPUTE SUM OF FLOW IN TRIBUTARY QSUM = QUP + QI + QS + QDIL
COMPUTE BOD OF DILUTION WATER (POUNDS) BODDP = 5.39* BODD * QDIL
RESET VARIABLES FOR NEXT REACH QBUP = 0.0 BODBE = 0.0 DOBEP = 0.0 BODTUT = 0.0 DOTUPT = 0.0 BODTU = 0.0 QTUP = 0.0 DOTUP = 0.0
IS THIS AN UPPERMOST REACH?
COMPUTE DEFICIT OF DILUTION WATER (POUNDS) DDP = 5.39* DD * QDIL
IS THERE ANY STORAGE AVAILABLE IN REACH?
COMPUTE SUM OF BOD IN THIS BRANCH (POUNDS) SUMBOD = BODBE +BODSP + BODIP + BODDP
INCREMENT COUNT ON SOURCES OF FLOW AUGMENTATION IN MAIN STEM
COMPUTE DO AT SATURATION IN POUNDS DOSAP = 5.39* DOSAT * QSUM
IS THIS THE 2ND TRIBUTARY BEFORE REACHING MAIN STEM?
INCREMENT COUNT ON SOURCES OF FLOW AUGMENTATION FOR FIRST TRIBUTARY
COMPUTE SUM OF DEFICIT IN BRANCH (POUNDS) DEFSUM = (DOSAP DOBEP DOSP) +DIP + DDP
INCREMENT COUNT ON SOURCES OF FLOW AUGMENTATION ON SECOND TRIBUTARY
COMPUTE BOD AND DEFICIT OF DILUTION FLOW IN POUNDS BODDP = 5.39* BODD * QDIL DDP = 5.39* DD*QDIL
COMPUTE SUM OF BOD IN POUNDS SUMBOD=BODTU +BODSP+BODSP +BODIP+BODDP
COMPUTE DO AT SATURATION IN POUNDS
COMPUTE SUM OF DEFICIT IN POUNDS
RESET VARIABLES FOR NEXT REACH
COMPUTE DO AT CRITICAL POINT IN PPM
COMPUTE DEFICIT AT CRITICAL POINT IN PPM
SET CRITICAL DEFICIT = TO DEFICIT AT HEAD OF REACH
SET MILES TO CRITICAL POINT TO REACH LENGTH
COMPUTE DEFICIT AT CRITICAL POINT IN POUNDS
DOES CRITICAL TIME APPROACH 0?
SET TIME TO CRITICAL POINT = TO TIME TO END OF REACH
DOES CRITICAL POINT FALL WITHIN THIS REACH?
SET CRITICAL DEFICIT = TO DEFICIT AT END OF REACH
IS DEFICIT AT END > 0? (IS DEND > 0?)
SET DEFICIT AT END = 0.0 DEND = 0.0
COMPUTE DEFICIT AT END OF REACH (POUNDS)
COMPUTE TIME TO END OF REACH (DAYS)
COMPUTE MILES TO CRITICAL POINT
DOES TIMEK APPROACH 0?
SET TIMEK TO 0 TIMEK=0.0
COMPUTE TIME TO CRITICAL POINT (DAYS)
COMPUTE VELOCITY
DOES REK1 = REK2?
REK2 = REK2 + 0.01 (TO AVOID DIVISION BY 0)
REK1 TO BASE e
COMPUTE K2
RESET QSUM QSUM = QSUMP
COMPUTE NEW DEFSUM = RATIO * DEFSUM
COMPUTE NEW SUMBOD = RATIO * SUMBOD
DETERMINE RATIO OF QSUM TO QSUMP
COMPUTE NEW QSUM
YES
NO

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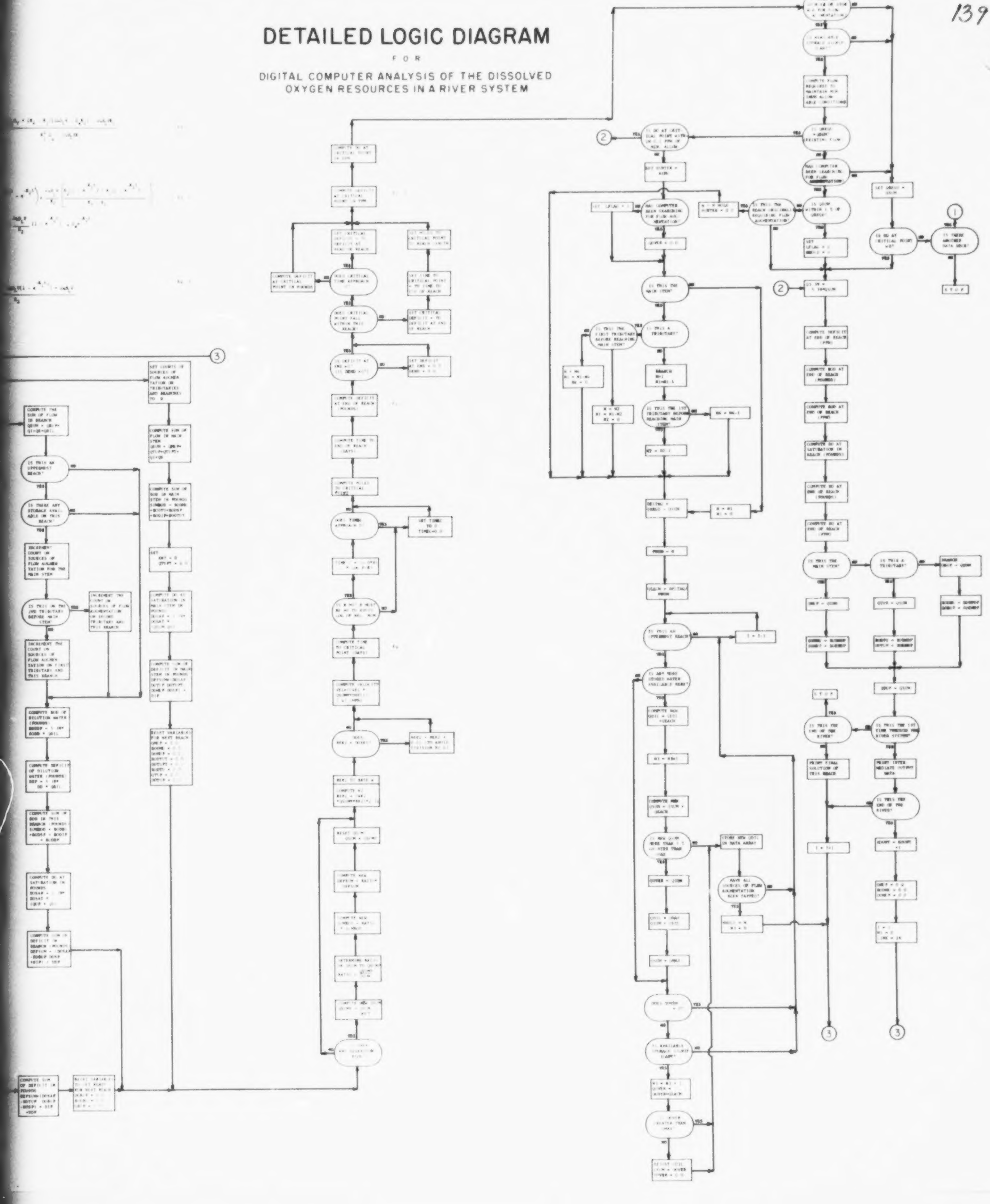
DETAILED LOGIC DIAGRAM

FOR

DIGITAL COMPUTER ANALYSIS OF THE DISSOLVED
OXYGEN RESOURCES IN A RIVER SYSTEM


COMPUTE FLOW REQUIRED TO MAINTAIN MINIMUM ALLOWABLE CONDITIONS
HAS COMPUTER BEEN SEARCHING FOR FLOW AUGMENTATION?
IS THERE ANOTHER DATA DECK?
STOP
IS THIS THE MAIN STEM?
IS THIS A TRIBUTARY?
COMPUTE DEFICIT AT END OF REACH (PPM)
COMPUTE BOD AT END OF REACH (POUNDS)
COMPUTE BOD AT END OF REACH (PPM)
COMPUTE DO AT SATURATION IN REACH (POUNDS)
COMPUTE DO AT END OF REACH (POUNDS)
COMPUTE DO AT END OF REACH (PPM)
IS THIS THE END OF THE RIVER?
PRINT FINAL SOLUTION OF THIS REACH
PRINT INTERMEDIATE OUTPUT DATA
IS THIS AN UPPERMOST REACH?
IS THIS THE 1ST TIME THROUGH THE RIVER SYSTEM?
STORE NEW QDIL IN DATA ARRAY
HAVE ALL SOURCES OF FLOW AUGMENTATION BEEN TAPPED?
QOVER = 0.0
PROD = 0
DELTAQ = QREQD - QSUM
YES
NO
①
②
③

NEW VARIABLE DEFINITIONS FOR OX SAG PROGRAM

TRTFAC - Treatment factor; this term identifies the portion of the raw load that is discharged to the receiving stream.

VARIDO - Variable dissolved oxygen objective.

NRUN - Run number.

L - Subscript for run number (NRUN).

J - Subscript for treatment factor (TRTFAC).

M - Subscript for variable DO objective (VARIDO).

T2 - Existing temperature - 20.0° C.

XK1T - K_1 at the temperature existing in the stream, or as adjusted from 20.0° C to the temperature recorded on the input data sheet under TEMP.

XK2T - The coefficient 'a' in the equation $k_2 = aQ^b$ adjusted from 20.0° C to the temperature existing in the stream or recorded on the input data sheet under TEMP.

CHANGES IN OPERATING INSTRUCTION

The program now has the capability of producing from 1 to 25 combinations of waste load and DO objective from a single deck of input cards. This replaces the old requirement of a deck of input cards for each combination of waste load and DO objective. This new capability is useful only in situations where a blanket change in waste loading or DO objective occurs.

The revised program accepts raw load in the BODS column on the input cards instead of the discharged load as used before. The raw load is then multiplied by the variable TRTFAC (treatment factor) which is actually the fraction of the raw load discharged to the receiving stream. For example if TRTFAC was 0.20, this would correspond to 80% BOD removal, 0.10 to 90% BOD removal, etc. TRTFAC is read in from a header card which will be described in a later paragraph.

Also the DOMIN column of the input cards is now normally coded with a 1.0 as the DO objective and multiplied by the value of VARIDO (variable DO) which is read in from a header card to be described in a later paragraph.

A run number for each combination of load and DO objective is read in from a header card. Up to 25 run numbers may be required; use only as many as required. A run number corresponds to one combination of waste load (TRTFAC) and DO objective (VARIDO).

These revisions necessitate the addition of one new header card which contains the run numbers and the modification of the existing one. The new header card comes first and contains up to 25 fields of 3 columns each with a format of I3 starting in column 1. Use only as many as needed; i.e., each field contains one three digit run number. The second header card is the one which now contains only k or the number of reaches in the system. This card is modified to include 6 fields of 4 columns each starting in column 4 with a format of F4.2 and 6 fields of 4 columns each beginning in column 28 with a format of F4.1. Use only as many of these fields as required but no more than five in either case. It is not necessary to fill the same number of fields for both variables. The first field containing all (0) zeros or blank indicates no more change in that variable. See attached sheet for layout of these two cards.

Also if this option is used it is necessary to punch a 1 in column 33 of Card I of reach number 0 instead of the 1 in column 32 of that same card as was done before revision.

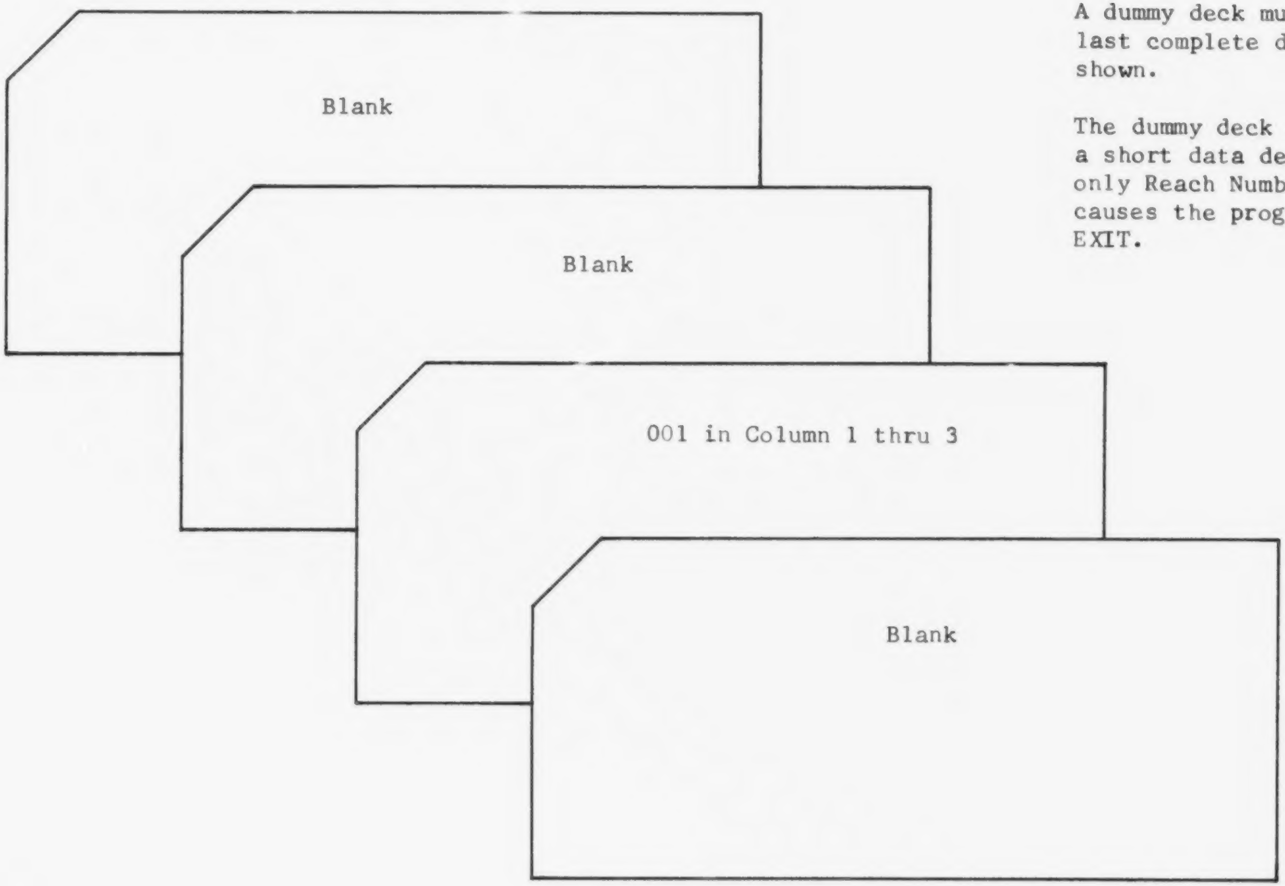
Also a dummy deck made up as shown on attached sheet must always follow the last data deck. This causes the program to CALL EXIT.

Another revision made more recently was the addition of a procedure to convert k_1 and k_2 values from 20° C to the temperature of the stream. This simplifies the development of input data in that values of k_1 and k_2 for 20° C are punched into the input cards and these values are adjusted to the temperature included on that same card. The new values for k_1 and k_2 are then stored in the data array along with all other input data.

DUMMY DECK

A dummy deck must follow the last complete data deck as shown.

The dummy deck is in effect a short data deck containing only Reach Number 0. This causes the program to CALL EXIT.

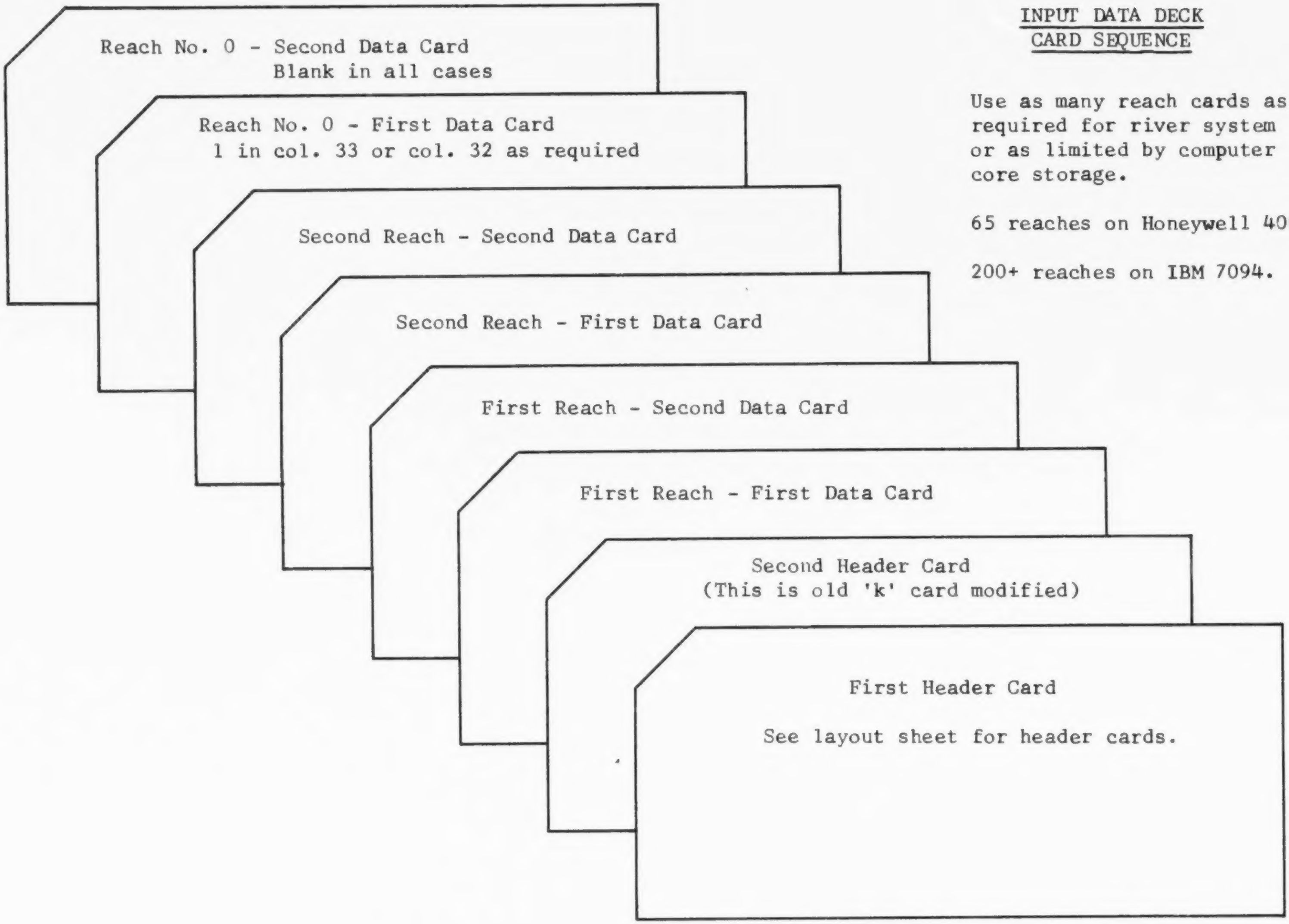

Blank
Blank
001 in Column 1 thru 3
Blank

INPUT DATA DECK
CARD SEQUENCE

Use as many reach cards as required for river system or as limited by computer core storage.

65 reaches on Honeywell 400.

200+ reaches on IBM 7094.


Reach No. 0 - Second Data Card
Blank in all cases
Reach No. 0 - First Data Card
1 in col. 33 or col. 32 as required
Second Reach - Second Data Card
Second Reach - First Data Card
First Reach - Second Data Card
First Reach - First Data Card
Second Header Card
(This is old 'k' card modified)
First Header Card
See layout sheet for header cards.

IBM

HEADER CARD LAYOUT

HEADER CARD 1   25 FIELDS AT 3 COLUMNS EACH   FØRMAT I3

```
001|002|003|004|005|006|007|008|009|010|011|012|013|014|015|016|017|018|017|020|021|022|023|024|025
140|141|142|143|144|145|
360|361|362|
```

USE AS MANY FIELDS AS NEEDED TØ ASSIGN
A THREE DIGIT NUMBER TØ EACH RUN

HEADER CARD 2   1 FIELD AT 3 COLUMNS, 12 FIELDS AT 4 COLUMNS

```
007|002.0|001.0|0005|    |    |    |0030|0050| 070|    |    |
025|001.5|    |    |    |    |    |0050|    |    |    |    |
143|001.5|    |    |    |    |    |0030|0040|0050|0060|0070|
```

FØRMAT CØL 1 THRU 3 I3
FØRMAT CØL 4 THRU 27 6F4.2
FØRMAT CØL 28 THRU 51 6F4.1

USE AT LEAST ØNE ØF EACH, NØT MØRE THAN FIVE FIELDS ØF EITHER ØF THE FØUR COLUMN GROUPS.

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```
      PROGRAM OXSAG
C     OXYGEN SAG PROGRAM
C     THIS PROGRAM IS DESIGNED TO DETERMINE THE FLOW IN CFS REQUIRED
C     IN A STREAM AT A GIVEN POINT TO MAINTAIN A MINIMUM STATED
C     DISSOLVED OXYGEN CONCENTRATION IN PARTS PER MILLION, IF REQUIRED
C     FLOW AT ANY POINT IS GREATER THAN THAT PRESENT, THE PROGRAM WILL
C     SEARCH THE RIVER SYSTEM FOR STORAGE RESERVOIRS FROM WHICH WATER
C     COULD BE RELEASED TO AUGMENT THE FLOW AND DETERMINE THE SIZE OF
C     RELEASE NECESSARY TO MEET DOWNSTREAM REQUIREMENTS.  DISSOLVED
C     OXYGEN CONCENTRATION IS THE ONLY QUALITY PARAMETER BEING
C     CONSIDERED.  ALL DECISIONS ARE BASED ON THIS PARAMETER
      DIMENSION QOVER(200)
      DIMENSION TRTFAC(6),VARIDO(6),NRUN(25)
      DIMENSION TAB(200,31)
    1 FORMAT(F4.0,F2.0,F5.1,F6.1,2F8.0,F6.1,F6.2,F6.1,3F4.1,F7.0/
     22F5.1,F4.1,F6.3,2F8.5,F8.6,F6.3,2F5.1,2F6.0)
   14 FORMAT(1H1,15HNO OF REACHES =,I4,10X,14HDO OBJECTIVE =,F4.1,10X,
     221HFRACTION DISCHARGED =,F4.2,10X,11HRUN NUMBER ,I5,10X,4HPAGE,I4)
   15 FORMAT(25I3)
   99 READ INPUT TAPE 5,15,(NRUN(L),L=1,25)
      READ INPUT TAPE 5,103,K,(TRTFAC(J),J=1,6),(VARIDO(M),M=1,6)
  103 FORMAT(I3,6F4.2,6F4.1)
      DO 110 I = 1,K
      READ INPUT TAPE 5,1,TAB(I,1),TAB(I,2),TAB(I,3),TAB(I,4),TAB(I,5),
     2TAB(I,6),TAB(I,7),TAB(I,8),TAB(I,9),TAB(I,10),TAB(I,11),TAB(I,12),
     3TAB(I,13),TAB(I,14),TAB(I,15),TAB(I,16),TAB(I,17),TAB(I,18),
     4TAB(I,19),TAB(I,20),TAB(I,21),TAB(I,22),TAB(I,23),TAB(I,24),
     5TAB(I,25)
      T2 = (TAB(I,14) - 20.0)
      XK1T = (TAB(I,17)) * 1.047 ** T2
      XK2T = (TAB(I,18)) * 1.0159 ** T2
      TAB(I,17) = XK1T
  110 TAB(I,18) = XK2T
      L=1
      J=1
   16 M=1
    3 DO 65 I=1,K
      QOVER(I) = 0.0
   65 CONTINUE
      I=1
      LPAGE = 1
      KOUNT = 0
      HUNTER = 0.0
      LFLAG = 0
      N1 = 0
      LINE = 54
      N2 = 0
      N4 = 0
      N3 = 0
      QMUP = 0.0
      BODBU = 0.0
      BODTU = 0.0
      BODMU = 0.0
      DOBUP = 0.0
      DOTUP = 0.0
      DOMUP = 0.0
      KNT = 0
    2 QDIL = TAB(I,5)
      TAB(I,30) = QDIL
      BODSP=5.39*TAB(I,24)*TRTFAC(J)*TAB(I,8)
      TAB(I,26) = BODSP
      DOSP = 5.39 * TAB(I,10) * TAB(I,8)
      TAB(I,27) = DOSP
      BODIP = 5.39 * TAB(I,22) * TAB(I,7)
      TAB(I,28) = BODIP
      DIP = 5.39 * TAB(I,11) * TAB(I,7)
      TAB(I,29) = DIP
      TAB(I,31)=VARIDO(M)*TAB(I,16)
      I = I + 1
      IF(1.0 - TAB(I,1))2,2,70
   70 I = 1
    4 IF(2.0 - TAB(I,2))27,6,6
    6 IF(1.0 - TAB(I,2))7,23,72
    7 IF(1.0-TAB(I,5))111,111,121
  111 IF(LFLAG-1)11001,11000,77
11001 KNT=KNT+1
11000 IF(2-KNT)77,115,116
  115 QTUPT = QTUP
      BODTUT = BODTU
      DOTUPT = DOTUP
  116 QTUP = 0.0
      QBUP = 0.0
      BODTU = 0.0
      DOTUP = 0.0
  121 QUP = QTUP + QBUP
      QSUM = QUP + TAB(I,7) + TAB(I,8) + TAB(I,30)
      IF(1.0 - QUP)8,8,9
    9 IF(1.02 * TAB(I,6) - QSUM)77,201,201
  201 IF(0.98 * TAB(I,6) - QSUM)8,8,10
   10 N1 = N1 + 1
      IF(2-KNT)77,311,310
  311 N4 = N4+1
      GO TO 8
  310 N2 = N2+1
    8 BODDP = 5.39 * TAB(I,23) * TAB(I,30)
      DDP = 5.39 * TAB(I,12) * TAB(I,30)
      SUMBOD = BODTU + BODBU + TAB(I,26) + TAB(I,28) + BODDP
      DOSAP = 5.39 * TAB(I,15) * (QUP + TAB(I,8))
      DEFSUM = (DOSAP - DOTUP - DOBUP - TAB(I,27)) + TAB(I,29) + DDP
      DOBUP = 0.0
      BODBU = 0.0
      QBUP = 0.0
      GO TO 101
   23 QSUM = QBUP + TAB(I,8) + TAB(I,7) + TAB(I,30)
      IF (1.0 - QBUP)26,26,24
   24 IF(1.02 * TAB(I,6) - QSUM)77,202,202
  202 IF(0.98 * TAB(I,6) - QSUM)26,26,25
   25 N1 = N1 + 1
      IF(2-KNT)77,124,125
  124 N4 = N4 + 1
      GO TO 26
  125 N2 = N2 + 1
   26 BODDP = 5.39 * TAB(I,23) * TAB(I,30)
      DDP = 5.39 * TAB(I,12) * TAB(I,30)
      SUMBOD = BODBU + TAB(I,26) + TAB(I,28) + BODDP
      DOSAP = 5.39 * TAB(I,15) * (QBUP + TAB(I,8))
      DEFSUM = (DOSAP - DOBUP - TAB(I,27)) + TAB(I,29) + DDP
      GO TO 101
   27 N2 = 0
      N4 = 0
      QSUM = QMUP + QTUP + QTUPT + TAB(I,7) + TAB(I,8)
      SUMBOD = BODMU + BODTU + TAB(I,26) + TAB(I,28) + BODTUT
      KNT = 0
      QTUPT = 0.0
      DOSAP = 5.39 * TAB(I,15) * (QSUM - TAB(I,7))
      DEFSUM = (DOSAP-DOTUP-DOTUPT-DOMUP-TAB(I,27)) + TAB (I,29)
      BODTUT = 0.0
      DOTUPT = 0.0
      BODTU = 0.0
      QTUP = 0.0
      DOTUP = 0.0
      QMUP = 0.0
      BODMU = 0.0
      DOMUP = 0.0
  101 IF(1.0 - TAB(I,9))17,18,18
   17 QSUMP = QSUM - TAB(I,9)
      RATIO = QSUMP / QSUM
      SUMBOD = RATIO * SUMBOD
      DEFSUM = RATIO * DEFSUM
      QSUM = QSUMP
   18 REK2 = (TAB(I,18) * QSUM **TAB(I,19))*2.31
      IF (REK2 - TAB(I,17))181,180,181
  180 REK2 = REK2 + 0.010
  181 VEL = (TAB(I,20) * QSUM ** TAB(I,21))/1.47
      X = REK2 - TAB(I,17)
      Y = TAB(I,17) * REK2
      Z = 24.0 * TAB(I,25) * VEL
      ZSL = 24.0 * TAB(I,13) * VEL
      W = (Y*SUMBOD) + (X * (ZSL - REK2 * DEFSUM))-(Z*TAB(I,17))
      U =(TAB(I,17) ** 2.0 * SUMBOD) -(TAB(I,17)*Z)
      R = W / U
      IF(R-0.00)20,20,80
   80 TIMEC = (1.0 / X) * LOGF(R)
      IF (TIMEC - 0.02)20,20,19
   20 TIMEC = 0.0
   19 CRMILE = 24.0 * VEL * TIMEC
      TEND = TAB(I,3) / (24.0*VEL)
      E = 2.71828
      A = E**(-TAB(I,17)*TEND)
      B = E ** (- REK2 * TEND)
      C1 = TAB(I,17) * SUMBOD
      C = (C1 / X) * (A - B)
      F = REK2 * (1.0 -A)
      G = TAB(I,17) * (1.0 - B)
      AA = Z / REK2
      BB = ZSL / REK2
      DEND = C + (AA *((F-G)/X)) + (BB *(1.0 - B)) + (B * DEFSUM)
      IF (DEND - 0.0)810,811,811
  810 DEND = 0.0
  811 IF (TAB(I,3) -CRMILE)21,21,81
   81 IF (0.02 - TIMEC)22,22,82
   82 DCLBS = DEFSUM
      GO TO 12
   21 DCLBS = DEND
      TIMEC = TEND
      CRMILE = TAB(I,3)
      GO TO 12
   22 CC = E ** (-TAB(I,17)*TIMEC)
      CC1 = TAB(I,17) * CC * SUMBOD
      DCLBS = (CC1 + (Z * (1.0 - CC)) + ZSL) / REK2
   12 DCPPM = DCLBS / (5.39 * QSUM)
      DOCPPM = TAB(I,15) - DCPPM
      IF(2.0-TAB(I,2))87,88,88
   87 IF (1 - N1)213,213,32
```

```
 88 IF(N2)77,32,213
213 IF(1.02 * TAB(I,6) - QSUM)77,203,203
203 IF(0.98 * TAB(I,6) - QSUM)32,32,28
 28 QREQD = QSUM * (TAB(I,15)-DOCPPM)/(TAB(I,15)-TAB(I,31))
    IF (QSUM - QREQD)35,29,29
 29 IF(LFLAG - 1)32,30,77
 30 IF(0.01 * QSUM - ABSF(QSUM - QREQD))31,33,33
 31 IF(HUNTER - TAB(I,1))34,90,90
 90 N = NHOLD
    HUNTER = 0.0
    GO TO 44
 32 QREQD = QSUM
    IF(DOCPPM)77,77,34
 33 LFLAG = 0
    NHOLD = 0
 34 Q539 = 5.39 * QSUM
    DENDPM = DEND / Q539
    BODNDP = SUMBOD * A
    BODEND = BODNDP / Q539
    DOSAP = Q539 * TAB(I,15)
    DOENDP = DOSAP - DEND
    DOEND = DOENDP / Q539
    IF(2.0 - TAB(I,2))37,38,38
 37 QMUP = QSUM
    BODMU = BODNDP
    DOMUP = DOENDP
    GO TO 41
 38 IF(1.0 - TAB(I,2))39,40,40
 39 QTUP = QSUM
    BODTU = BODNDP
    DOTUP = DOENDP
    GO TO 41
 40 QBUP = QSUM
    BODBU = BODNDP
    DOBUP = DOENDP
 74 FORMAT (1H ,2F5.0,F9.0,4F8.2,F7.1,2F9.3,3F8.1,F12.5,F7.3,F7.1)
 73 FORMAT(1H-,1X,4HRENO,2X,5HDIGIT,2X,4HQSUM,3X,6HDOCPPM,3X,5HDCPPM,
   23X,5HDOEND,2X,6HDENDPM,2X,6HBODEND,3X,5HTIMEC,4X,4HTEND,3X,
   36HCRMILE,3X,5HRFLEN,3X,5HRIVMI,6X,4HREK2,4X,5HDOXK1,3X,4HTEMP,/)
750 FORMAT(1H-,1X,4HRENO,2X,5HDIGIT,3X,4HQDUP,5X,3HVEL,3X,6HDOCPPM,
   23X,6HBODEND,/)
 41 QDUP = QSUM
    IF(1 - KOUNT)77,75,141
760 WRITE OUTPUT TAPE 6,14,K,VARIDO(M),TRTFAC(J),NRUN(L),LPAGE
    LPAGE = LPAGE + 1
    WRITE OUTPUT TAPE 6,750
    LINE = 0
141 IF(54-LINE)760,760,98
 98 WRITE OUTPUT TAPE 6,74, TAB(I,1),TAB(I,2),QDUP,VEL,DOCPPM,BODEND
    LINE = LINE + 1
 72 IF(1.0 - TAB(I,1))79,79,71
 71 KOUNT = KOUNT + 1
    IF(2-KOUNT)77,77,42
 42 QMUP = 0.
    BODMU = 0.0
    DOMUP = 0.0
    N1 = 0
    I = 1
    LINE = 54
    GO TO 4
 75 IF(1.0 - TAB(I,1))762,762,1103
762 IF(54-LINE)763,763,76
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763 WRITE OUTPUT TAPE 6,14,K,VARIDO(M),TRTFAC(J),NRUN(L),LPAGE
    LPAGE = LPAGE + 1
    WRITE OUTPUT TAPE 6,73
    LINE = 0
 76 WRITE OUTPUT TAPE 6,74,TAB(I,1),TAB(I,2),QSUM,DOCPPM,DCPPM,DOEND,
   2DENDPM,RODEND,TIMEC,TEND,CRMILE,TAB(I,3),TAB(I,4),REK2,TAB(I,17),
   3TAB(I,14)
    LINE = LINE + 1
 79 I = I + 1
    GO TO 4
 77 CONTINUE
102 FORMAT(1H-,1X,4HRENO,2X,4HHUNT,2X,5HDIGIT,2X,5HTIMEC,3X,3HKNT,2X,
   25HKOUNT,4X,2HN2,4X,2HN4,4X,2HN1,4X,2HN3,2X,5HLFLAG,5X,5HQREQD,7X,
   35HQOVER,8X,4HQSUM,4X,1HN,4X,6HDOCPPM)
1102 FORMAT(1H ,3F6.0,F7.3,7I6,3F12.0,I5,F7.2)
1103 WRITE OUTPUT TAPE 6,102
    WRITE OUTPUT TAPE 6,1102,TAB(I,1),HUNTER,TAB(I,2),TIMEC,KNT,KOUNT,
   2N2,N4,N1,N3,LFLAG,QREQD,QOVER(I),QSUM,N,DOCPPM
    IF(1.0-TAB(I,6))99,11,113
 11 L=L+1
    M=M+1
    IF(VARIDO(M))77,5,3
  5 J=J+1
    IF(TRTFAC(J))77,99,16
113 STOP
 35 IF(0.10 - ABSF(DOCPPM - TAB(I,31)))36,33,33
 36 HUNTER = TAB(I,1)
    IF(LFLAG - 1)43,45,77
 43 LFLAG = 1
    GO TO 44
 45 QOVER(I) = 0.0
 44 IF(2.0 - TAB(I,2))46,47,47
 47 IF(1.0 - TAB(I,2))48,49,49
 49 N = 1
    N1 = N1 -1
    IF(2-KNT)77,126,127
126 N4 = N4 - 1
    GO TO 50
127 N2 = N2 - 1
    GO TO 50
 48 IF(2-KNT)77,147,148
147 N = N4
    N1 = N1 -N4
    N4 = 0
    GO TO 50
148 N = N2
    N1 = N1 - N2
    N2 = 0
    GO TO 50
 46 N = N1
    N1 = 0
    KNT = 1
 50 DELTAQ = QREQD - QSUM
    FNUM = N
    QEACH = DELTAQ / FNUM
 52 IF(1.0 - TAB(I,5))53,53,51
 51 I = I - 1
    GO TO 52
 53 IF(TAB(I,6)-(TAB(I,30)+TAB(1,7)+TAB(I,8)))54,54,55
 55 QOIL = TAB(I,30) + QEACH
    IF(N)77,58,64
 64 N3 = N3 +1
```

```
      QSUM = QDIL + TAB(I,7) + TAB(I,8)
      IF(1.01 * TAB(I,6) - QSUM)57,61,61
   57 QOVER(I) = QSUM
      QDIL = TAB(I,6) - QSUM + QDIL
      QSUM = TAB(I,6)
   61 TAB(I,30) = QUIL
      IF(N - N3)77,59,51
   59 NHOLD = N
      N3 = 0
      QBUP = 0.0
      BODAU=0.0
      GO TO 4
   54 QSUM = TAB(I,30)+TAB(I,7)+TAB(I,8)
      IF(1.0-QOVER(I))69,56,56
   56 IF(I-N)51,58,58
   58 QSUM = TAB(I,6)
      TAB(I,30)=QSUM-(TAB(I,7)+TAB(I,8))
      GOTO 59
   69 IF(1.02 * TAB(I,6) - QSUM)77,205,205
  205 IF(0.98 * TAB(I,6) - QSUM)51,51,60
   60 N3 = N3 + 1
      QOVER(I) = QOVER(I) + QEACH
      IF(QOVER(I) - TAB(I,6))62,62,61
   62 QDIL = QOVER(I) - QSUM + QDIL
      QSUM = QOVER(I)
      QOVER(I) = 0.0
      GO TO 61
      END

        3200 FORTRAN DIAGNOSTIC RESULTS - FOR   OXSAG


NO ERRORS
EQUIP,05=60,06=61
LOAD,56
RUN,
```